RENEWABLE ENERGY RESOURCE ASSESSMENT PLAN

Phase 1: Renewable Energy Resource Assessment And Development Program

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APPENDICES

LIST OF ACRONYMS

ACI	Augustyn & Company, Inc.
ALISH	Agricultural Lands of Importance to the State of Hawaii
DBEDT	Department of Business, Economic Development & Tourism
DNI	direct normal (broad band) irradiance
DVS	data verification system
GHI	global horizontal (broad band) irradiance
HELCO	Hawaiian Electric Light Company
HES	Hawaii Energy Strategy
HNEI	Hawaii Natural Energy Institute
HNRIS	Hawaii Natural Resources Information System
HSPA	Hawaiian Sugar Planters' Association
NELH	Natural Energy Laboratory of Hawaii
NREL	National Renewable Energy Laboratory
OTEC	ocean thermal energy conversion
PICHTR	Pacific International Center for High Technology Research
RLA	RLA Consulting
RSR	rotating shadow band radiometer
SRIC	short-rotation intensive culture
WMO	World Meteorological Organization

SUMMARY

RLA Consulting (RLA) has been retained by the State of Hawaii Department of Business Economic Development & Tourism (DBEDT) to conduct a Renewable Energy Resource Assessment and Development Program. This report summarizes the results of Phase 1 of this program. The purpose of Phase 1, entitled Development of a Renewable Energy Resource Assessment Plan, is to better define the most promising potential renewable energy projects and to establish the most suitable locations for project development in the state. In addition, a monitoring plan was developed to obtain additional wind and solar resource data in areas with development potential. Future work on this program will include the collection of the data, the quantification of the costs and annual energy output for these projects, and the development of resource supply curves.

In order to identify possible renewable energy project sites with significant development potential, RLA determined constraints and requirements for renewable energy projects for six different renewable energy resources: wind, solar, biomass, hydro, wave, and ocean thermal. Consideration of geothermal energy was added to this investigation under a separate contract with DBEDT. A screening process was used to identify the most promising project locations based on factors such as resource intensity, land availability, environmental constraints, utility interconnection, zoning, and public acceptance. For this phase of the project, the emphasis for project identification was on utility-scale, grid-connected renewable energy projects, however, potential applications for small, distributed uses were identified where appropriate.

Hawaii has an abundance of renewable energy resources. For most renewable energy technologies, a sufficient resource exists on each island to warrant consideration of an energy project. With few exceptions, issues other than the resource were the determining factor in identifying projects with development potential. Because these other issues (e.g., public acceptance, land availability, land ownership, utility grid size) are subject to change over time, the project lists identified in this report should be considered in the context of existing conditions. Future developments may either enhance or decrease the opportunities for renewable energy projects. For example, utility interconnection of the islands or significant load growth could increase potential project sizes. However, the land uses associated with the reasons for load growth may conflict with potential renewable energy projects. Other examples of factors that could impact project development in the future include the changing nature of the military presence, which may free up large parcels of land, and increased public acceptance of the visual impact of wind turbines.

Despite the limitations noted below, a significant number of renewable energy projects that have substantial development potential were identified on each island. As a result of the elimination process, the projects represent realistic opportunities for developing renewable energy in the State of Hawaii. These projects would result in renewable energy making a significant contribution to Hawaii's energy mix. Quantifying this contribution is the subject of future phases of this program.

A review of the existing wind and solar data and the potential project sites that were identified for these technologies was the basis for developing a monitoring plan for additional data collection. Existing, high-quality data sets and monitoring stations were identified and these data will be incorporated into the monitoring program. Ten additional wind monitoring stations and six additional solar monitoring stations were recommended.

One of the largest factors in eliminating potential projects from consideration is the availability of land without conflicting or competing land uses. Only on Hawaii and the lightly populated islands of Lanai

and Molokai were sites identified in which the potential for competing land uses were not considered to be an issue. This is not to say that development of projects is impossible on the other islands; only that the demand for land is high and the impact of an energy project on a particular site will be weighed against other potential uses for that land as well as any potential impacts on activities on surrounding lands. Primary competing land uses include urban expansion (primarily housing and light industry), conservation, and agriculture.

The total generating capacity of the utility grid on each island also limits potential development, particularly of intermittent generating technologies. Changes in the operating characteristics of the utilities, incorporation of energy storage, widespread use of electric vehicles, or island interconnection are factors that could alter this condition. As a result, projects were not eliminated from consideration on this basis. Nonetheless, the small grid capacity and growth projections of Lanai and Molokai preclude large-scale project development in the near future. Small-scale renewable energy projects (less than 50 kW) are best suited for these islands, either through demand side or dispersed generation applications. Given the relatively high energy cost on these islands, small-scale renewable energy projects should be economical on a widespread basis and have the potential to make a significant contribution to reducing petroleum dependency. On the other islands, utility-scale projects (1 MW or larger) are technically feasible. Although small-scale renewable energy applications are also likely to be possible at many locations on these islands, larger projects will make a more substantial contribution.

On Maui, Kauai, and Oahu, the majority of the mountainous land is restricted to either parks or forest reserves and the coastlines are either restricted from development or developed for urban uses or tourism. As a result, land-intensive energy projects are difficult to site in areas other than those used for agricultural purposes. Most of the biomass energy crop projects assume replacement of existing crops with an energy crop. A number of the wind and solar project sites also displace existing agricultural land uses. The likelihood of these projects depends heavily on market trends for the existing crops, particularly sugar. The sugar industry in Hawaii is on the decline with only a few economically viable plantations remaining. In many cases, land previously devoted to the production of sugarcane in these areas could be used for biomass crops or other renewable technologies.

The OTEC, hydro, and wave energy projects may require the use of highly protected shorelines or streams. Public acceptance of these projects is expected to be a major hurdle. However, the public perception of all energy projects is difficult to quantify and subject to change. For example, in Europe, wind turbines are often sited in highly populated areas that might be considered unacceptable in the United States. As these technologies become more common, public perception of their use, particularly in terms of visual impacts, are likely to change.

SECTION 1. INTRODUCTION

RLA Consulting (RLA) has been retained by the State of Hawaii Department of Business, Economic Development & Tourism (DBEDT) to conduct a Renewable Energy Resource Assessment and Development Program. This three-phase program is part of the Hawaii Energy Strategy (HES), which is a multi-faceted program intended to produce an integrated energy strategy for the State of Hawaii. The purpose of Phase 1 of our project, Development of a Renewable Energy Resource Assessment Plan, is to better define the most promising potential renewable energy projects and to establish the most suitable locations for project development in the state. In order to accomplish this goal, RLA has identified constraints and requirements for renewable energy projects from six different renewable energy resources: wind, solar, biomass, hydro, wave, and ocean thermal. These criteria were applied to areas with sufficient resource for commercial development and the results of Phase 1 are lists of projects with the most promising development potential for each of the technologies under consideration. Consideration of geothermal energy was added to this investigation under a separate contract with DBEDT. In addition to the project lists, a monitoring plan was developed with recommended locations and a data collection methodology for obtaining additional wind and solar data. This report summarizes the results of Phase 1.

The technologies considered in this project were prioritized based on their commercial status and their ability to contribute to Hawaii's energy mix. For this phase of the project, the emphasis for project identification was on utility-scale, grid-connected renewable energy projects. Although small-scale, demand-side or small-scale, dispersed-generation projects have the potential to reduce Hawaii's oil dependency, their application is more difficult to quantify because, in most cases, their adoption is based on subjective factors such as a home owner's willingness to invest capital. Also, the factors that were considered in this phase of the program, such as land availability, environmental constraints, utility interconnection, and zoning, do not generally apply to small-scale systems. However, these types of projects are included in the project list and their contribution and economics will be considered in greater depth in later phases of the program.

Biomass and hydroelectric are the most commercially proven renewable technologies available in Hawaii and, in relation to their potential, both of these have been used extensively in the state. In this project, the investigation of additional hydroelectric projects was fairly limited because most potential hydroelectric projects have been previously identified. In addition, the majority of these potential projects are fairly limited in capacity and the likelihood of implementing new hydroelectric projects is small due to strong opposition to new projects, a complex permitting process, and a pending policy from the State of Hawaii Office of State Planning regarding the classification of Hawaii's streams and development guidelines.

Biomass, through the sugar industry in Hawaii, has been used extensively throughout the state. Additional opportunities exist in terms of both the use of crops for energy (for either transportation fuels or conversion to electricity) and municipal solid waste. For biomass, Phase 1 of this project concentrated on identifying the most appropriate energy crop for the available agricultural lands and quantifying the municipal solid waste.

Wind and solar technologies have more recently entered the commercial market and, although the power output from these sources tends to be intermittent, their energy potential remains largely untapped. Additional resource assessment work for these technologies offers the most potential for promoting an increase in the use of renewable energy sources in Hawaii. As a result, identifying appropriate development sites for large-scale projects for these technologies and recommending additional monitoring sites was a primary objective of Phase 1. Of these technologies, wind is the most mature, and a number of wind energy developers have proposed projects in the state.

Wave and ocean thermal energy projects have considerable long-term potential in Hawaii, and several sites have been identified as potential locations for commercial projects. The commercial status of these technologies, however, does not at this time justify an in-depth analysis of potential sites at this time beyond what has already been completed. As the technology matures for these resources, the requirements and constraints may change considerably. For example, more than fifty different wave energy conversion technologies have been developed worldwide in the last decade [1]. Evaluating the range of possibilities for the most economical and best-suited technologies for potential project sites is beyond the scope of this report. For ocean thermal projects, future commercial power plants are envisioned as floating facilities. The impacts and requirements of such systems are not yet clearly defined. As a result, limited effort was expended on siting these technologies in Phase 1. A more in-depth analysis of their status and economics will be completed in future phases.

Geothermal energy conversion from high-temperature, water dominated resource areas is a mature technology that has been commercially deployed since the 1960's. Significant technological advances are not expected by the year 2005. One geothermal project has recently been installed on the Island of Hawaii in the Kilauea east rift zone. Even though this project was the subject of intense public opposition, further expansion in this same area is expected to be the most likely option for increased geothermal power development in the state.

The following sections describe the screening process that was used to identify the most promising renewable energy project sites, present the project lists for each technology, and describe the monitoring plan for additional wind and solar resource data.

SECTION 2. IDENTIFICATION OF POTENTIAL RENEWABLE ENERGY PROJECT SITES

APPROACH AND METHODOLOGY

For each of the technologies under consideration, a potential project list was developed based on an elimination process of the available land on each of the six major Hawaiian islands: Hawaii, Maui, Molokai, Lanai, Oahu, and Kauai. For each island, geographic areas were identified in which resource potential exists and an in-depth screening process was conducted that included consideration of factors such as land ownership, zoning, current and planned land uses, technology-specific development requirements, utility access and impact, environmental constraints, and public acceptance. For wind and solar, the project lists are the basis for the recommended monitoring plan. The following sections describe the approach and methodology for identifying project sites in terms of the screening factors.

RESOURCE INTENSITY

For each technology, geographic areas were identified in which sufficient resource was believed to exist to permit commercial development. The resource intensity was based on the best data currently available, either direct measurements or extrapolations from related information.

Wind: The areas with significant wind energy resource were identified based on a previously created wind atlas for the state of Hawaii, miscellaneous wind studies throughout the state, and RLA's independent assessment of the available data [2,3,4]. In addition, RLA considered areas in which data were not currently available but for which a significant resource was suspected to exist based on terrain or vegetation indicators. Field visits were performed at all potential resource areas to verify the available information and note any factors that could not be identified otherwise. The average annual wind speed, the wind speed distribution, and the height at which prior measurements were taken were considered in determining whether the resource was sufficient for commercial development.

Solar: Areas with significant solar resources were identified based on previously created solar maps (based primarily on Hawaiian Sugar Planters' Association data), miscellaneous solar studies throughout the state, RLA's independent assessment of the available data, and the average direct insolation estimated for various locations as compared to a long-range station at the University of Hawaii at Manoa [5]. All potential resource areas were surveyed during the field visits. Both global and direct (when available) solar radiation data were considered in determining whether the resource was sufficient for commercial development.

Biomass: Two types of biomass energy crops were considered: short-rotation intensive culture (SRIC) tropical hardwoods, and grass crops specifically cultivated as a biomass feed stock. The biomass energy wood crop resource was estimated as expected crop yields per acre of land based on information from the Hawaii Natural Resources Information System (HNRIS) geographical information system and database developed by the University of Hawaii. HNRIS considers both the soil and climatic conditions for individual areas to determine the crop yields for specific plant species.

For grass crops, the assumption was made that each existing sugar plantation has the potential to be the location of a grass crop plantation because it is highly likely that an energy grass crop would be closely related to sugar itself. However, short rotation grass crops, tailored specifically for biomass to energy conversion are easier to grow, easier to harvest, and less cumbersome to transport than sugarcane. The potential for grass crop yield was estimated based on historical yields from the plantations as published by the HSPA. These estimates are expected to be conservative since the species of grass crop for biomass-to-energy facilities will be chosen to optimize yield at the specific location while sugarcane is grown specifically for sugar production. In comparison to sugarcane, grass crops can be expected to be faster growing, yield a higher dry weight per acre, have a lower water content, and be easier to harvest and process for use. While the yield was based on actual sugarcane production values, costs for the installation and operation of the facilities was based on techniques consistent with biomass-for-energy facilities. On Molokai, a banagrass crop was considered. Information on areas of planted cane and annual harvested amounts of cane were derived from the 1992 Hawaiian Sugar Manual. The information concerning a banagrass crop on Molokai was obtained from Dr. Charles Kinoshita, Hawaii Natural Energy Institute.

Another biomass technology considered was converting organic waste material to energy and other by-products. The resource for organic waste conversion is the number of tons of organic waste per year for each island or region within an island. Data for organic waste generation were obtained from a recent survey of Hawaii's organic waste potential that was completed for DBEDT by Unisyn [6]. The energy end-product that is converted from trees, grass, or organic waste can be methanol, ethanol, or electricity.

Hydroelectric: All significant streams and irrigation ditches were considered as potential hydroelectric resources. The resource potential for this technology is based on the available head and annual stream flow. Areas with development potential were determined based on a survey of all of Hawaii's streams and rivers [7]; however, due to the difficulty involved in siting hydroelectric facilities, locations investigated were restricted to existing or currently proposed hydroelectric facilities [8,9]. Final project sites were selected based on the predicted availability of projects to successfully complete the permitting and public review process.

Wave and OTEC: The wave and OTEC resource for tropical islands, and specifically for the Hawaiian islands, has been shown to be virtually boundless [1]. The ocean thermal resource is determined largely by the bathymetry of the ocean. The wave resource is defined by the wave spectrum for various sea states. Because of the commercial status of these technologies, however, project locations were restricted to the locations that have been previously evaluated and for which detailed resource information is currently available. No attempts were made to evaluate the resource availability in areas that have not been previously identified. For OTEC, the resource locations and potential project sites were based on work conducted by the Natural Energy Laboratory of Hawaii (NELH) and Pacific International Center for High Technology Research (PICHTR) [10,11]. For wave energy, the resource locations and potential project sites were based on a wave resource assessment study conducted for DBEDT [1].

Geothermal: The Hawaiian islands are a volcanic island chain. The volcanic structures are an obvious source of a potential geothermal resource. While the theoretical geothermal energy potential in the state is virtually boundless, development of such projects has been seen to be highly controversial. Since future development is likely to be highly restricted, this study examines the cost and performance of new power generation projects in the immediate vicinity of the recently completed facility in the Kilauea east rift zone. The most accessible, developable geothermal resource in the Kilauea east rift zone is characteristically a high-temperature, water-dominated resource area.

LAND ZONING

The state-wide system of land zoning defines land districts as either Urban, Rural, Agricultural, or Conservation. The Conservation district is further divided into areas of General, Limited, Special, and Protective subzones. In addition, land may be further classified as Shoreline. Each of these land use districts and subzones has specific regulations as to the allowable land uses and permitting processes required. The boundaries of these districts are periodically reviewed by the Office of State Planning. While modifications are made, the practices allow the state to encourage or discourage various land use activities (i.e., policy or legislative changes could make more land available for renewable energy development). Projects were identified in this report based on current zoning practices. Preliminary zoning maps were developed based on the information contained in the HNRIS database (see Appendix A). Within each of the geographic areas identified as having resource potential, RLA verified the land zoning and determined the subzoning based on the most currently available zoning maps from the State Land Use Commission and the Conservation Division of the Department of Land and Natural Resources. For each of the resources under consideration, land was screened as follows:

Wind: There is specific wording that allows wind energy development in Agricultural districts, and it is anticipated that, barring conflicting land uses, wind energy will be allowable in Rural districts. It is foreseeable that, with some permitting requirements, wind energy projects could be developed in Conservation district subzones labeled as Resource and General. The elimination criteria used for wind sites are as follows:

1. No reasonable expectation of development in the following areas: Urban districts and Protective, Limited, and Special Conservation subzones. (Note: Federal land used for military purposes that is zoned urban was not necessarily eliminated if current land use practices permit consideration of a renewable energy project.)

2. Limited expectations of development in the following areas: Resource and General Conservation subzones.

3. No explicit land use barriers in the following areas: Rural and Agricultural districts.

Solar: It is anticipated that, barring conflicting land uses, solar energy will be allowable in Rural districts. It is foreseeable that solar energy projects could be developed in Agricultural districts where the soil is of quality C, D, E, or U, (denotes limited value for agricultural use) according to the ALISH system (Agricultural Lands of Importance to the State of Hawaii) and in Conservation district subzones labeled as Resource and General. The elimination criteria used for utility-scale solar sites are:

1. No reasonable expectation of development in the following areas: Urban districts and Protective, Limited, and Special Conservation subzones. (Note: Federal land used for military purposes that is zoned urban was not necessarily eliminated if current land use practices permit consideration of a renewable energy project.)

2. Limited expectations of development in the following areas: Resource and General Conservation subzones, and Agricultural Districts (where soil is of C, D, E, or U quality; county approval is required).

3. No explicit land use barriers in the following areas: Rural Districts.

Biomass: Only land currently zoned for Agriculture was considered for energy crop biomass projects. The land availability scheme for biomass plantations was previously developed for use with the HNRIS system [12]. For this study, land availability was considered for the islands of Kauai, Maui, Molokai, and Hawaii. Previous work completed by the University of Hawaii indicated that land-intensive biomass energy crop projects would not be feasible on Oahu or Lanai. On Lanai, the sole landowner has committed to tourist development and, mainly because of the limited demand, is not interested in pursuing an energy crop project However, both the state and the city and county of Honolulu are interested in maintaining parts of Oahu as a green belt. One potential biomass project was considered on Oahu based on the conversion of current sugarcane land.

For organic solid waste projects, land zoning was not considered as a criteria for eliminating projects. The land requirements for a processing facility will by driven by the location of the waste stream, and, with the exception of protected conservation land, this type of facility should be feasible to site within any zoning category.

Hydro, Wave, OTEC, and Geothermal: These technologies are not land intensive, and, as such, were not eliminated based on land zoning. The majority of the hydro resource is located within conservation districts. Land-based wave and ocean thermal energy conversion facilities, by definition, are located in areas classified as shoreline. Due to the value of this limited land resource, sites for further development are likely to be based on the existing land use conditions rather than zoning. The proposed location for geothermal projects is in a previously identified resource area where recent project construction was completed but not with extensive public opposition. Further development anywhere in the state will likely be difficult.

TERRAIN SUITABILITY

In general, flat land is acceptable for any type of project. For the land-based technologies considered, steep, mountainous terrain or heavily forested land is not suitable for project development. In the state of Hawaii, most such lands were eliminated from consideration by zoning for resource conservation. Technology-specific terrain requirements such as slope, vegetation cover, and soil characteristics were also used as a criteria for eliminating land areas and ranking project sites. Wind energy and parabolic dish solar energy projects are relatively insensitive to topography, although the terrain may dictate the spacing and configuration of the array of units. Solar troughs and photovoltaic arrays for utility-scale applications require a more even slope. For example, solar trough technology, in particular, is best suited to areas where the slope is less than 2% and the soil is easily manipulated. As a result, a number of sites that were eliminated for solar trough projects were retained as potential solar dish or photovoltaic projects. Biomass crop requirements are similar to the existing needs of sugar cane or pineapple fields. Because these agricultural lands were the only lands considered for this study, terrain suitability is likely.

COMPETING USES

Land uses competing with energy production in Hawaii are related to the state's major industries: agriculture and tourism. The value of an energy project on a plot of land must be compared to the value of using that plot of land for a different purpose, without the energy project. The more significant land uses competing with energy projects include housing projects, golf courses, tourist resorts, crop farming, grazing, and environmental preservation. In some cases, land may be used for multiple purposes.

Current and planned land use were determined through a field survey of the areas under consideration, discussions with landowners, and discussions with county land use planners. In addition, the State Land Use District Boundary Review reports for each island were reviewed to determine the rationale for any potential land use re-classifications that may be undertaken by the State [13-16]. During the field surveys, areas with obvious land use conflicts (i.e., existing development) were eliminated from further consideration. The majority of the large landowners in Hawaii have long-term land use plans for the lands under their control. These plans, along with any long-term leases or contracts that impact land use, were discussed with the landowners as well as their positions on utilizing portions of their land for renewable energy projects. A common concern among landowners is the impact of a renewable energy project on other existing or planned uses on their land, particularly tourist development and agriculture.

Another factor to consider when replacing existing agricultural crops with more industrial energy projects is that the agricultural lands are often seen as a buffer between urban developments and areas used for conservation and tourism.

The majority of the land that is preserved or protected (i.e., parks, watershed, forest reserves) was previously eliminated based on zoning. Land slated for urban expansion or tourism development was also eliminated. The following additional factors were considered in screening for conflicting uses:

Wind: Wind energy is compatible with some agricultural uses, as the turbine foundations physically occupy only a small fraction of the project site's land area. The area between turbine foundations can be used for grazing or, in some cases, crop cultivation. In Hawaii, the two main crops, sugar, and pineapples, require harvesting techniques that are not as compatible with wind energy as other crops. Although there is no technical incompatibility with these crops, landowners and plantation managers have indicated that it may make their typical harvesting techniques more difficult. With pineapple cultivation, for example, the periodic location of wind turbine towers would greatly interfere with the equipment used to harvest pineapples. The burning of cane fields may also affect wind turbines. For this study, these agricultural uses were not used to eliminate land from consideration as a wind energy site unless the landowner specifically indicated that he would not consider development on his land. Grazing is considered to be compatible with wind energy, as has been demonstrated on the island of Hawaii, at the Lalamilo Wells wind farm and at Kahua Ranch.

Solar: Due to its land-intensive nature, solar energy conversion is incompatible with most agricultural uses. For this reason, the siting of solar projects was generally not considered in Agricultural districts that have been identified as either prime or unique according to the ALISH system unless the landowner indicated that he would consider the replacement of agricultural crops with this type of project if it was economical. Dish sterling solar technology may be compatible with some grazing uses. In addition, the reflection from solar projects must be considered so that it does not interfere with nearby activities.

Biomass: The ability to cultivate energy crops will depend largely on factors in the sugar, pineapple, and oil markets. For our study, a methodology was used to evaluate land availability based on five levels of land use sensitivity [12]. Only land parcels in the two most favorable land use sensitivity classes were considered to be available for SRIC tropical hardwood plantations. Land suitability for energy crops was based on both the intrinsic and manageable environmental conditions of a given site required by a given species to achieve a targeted yield. To determine land suitability for Eucalyptus grandis, eucalyptus saligna, and Leucaena leucocephala production, data were assembled from field experiments in Hawaii conducted by other investigators who are evaluating the performance of these species and provenances in different environments [17-24]. Information recorded for each experiment included growth age, mean diameter at breast height, mean height, initial planting density, survival rate, amount of nitrogen fertilizer applied, plot aspect (slope and direction), and elevation. Site variables included in the analysis were elevation, mean daily temperature, mean annual rainfall, mean daily solar radiation, soil nitrogen content, and soil Ph value. These site data were obtained from the literature or from the HNRIS database. For this study, all agricultural land with sufficient soil and climate conditions to provide acceptable yields were considered even if they were currently planted in another crop.

Energy production from organic waste conversion, as mentioned before, is not land intensive and is not impacted in the same way by competing land uses. Depending on the technology employed, the by-products from organic waste processing may be desirable for agricultural purposes, and it may be favorable to locate waste-to-energy conversion facilities near to, or on, agricultural lands. For organic waste, the transportation of the waste is a primary consideration and facilities are likely to be centrally located near existing landfills to take advantage of the in-place waste disposal transportation strategies.

Hydro: The main land use competing with hydroelectric power development is environmental preservation and recreation. Public opposition due to these factors is a primary consideration for siting hydro projects, and the primary factor likely to limit additional development in the State.

Wave and OTEC: The primary conflicting land use for any land-based ocean energy system is access and use of the shoreline. The island shorelines are very valuable for tourism, and other ocean access activities, so the future development of wave and OTEC projects is likely to meet with considerable competition unless there is a drastic increase in both the economic value of energy production and the cost of generating electricity from other sources.

The sites evaluated for this study were chosen to minimize any competing land use issues. As the technologies become more cost effective, competing land use issues will demand more attention.

Geothermal: The Kilauea east rift zone is zoned for both agricultural and conservation uses in about equal proportions. There is a minor amount of urban land. The conservation land occurs mainly on the western portion of the Kilauea east rift zone including the Hawaii Volcanoes National Park. The middle and lower zones are predominantly agricultural. Ownership in the lower zone includes state land and others. This area has been designated as a Geothermal Resource Subzone.

OWNER ACCEPTANCE

After completing the above screening process, the possibility of a renewable energy project was discussed with the landowners of the remaining land areas that appeared suitable. Preliminary land ownership classifications were determined from HNRIS (see Appendix B). Tax key maps were reviewed for more detailed information regarding ownership of specific parcels and private land. The likelihood of the development of an energy project is highly dependent on how it will affect the overall income of the landowner. The cost of producing energy must not only compare favorably with the price obtained by selling the energy, the project will also be judged on how it affects the profitability of planned land uses of surrounding lands. Most power generating technologies are not directly compatible with tourism activities due to visual impact, so a landowner that plans a vacation resort will often be unwilling to site an energy project on nearby land. In the case of wind energy, several landowners have even indicated the concern that the visible presence of wind turbines may imply that their resort is frequently windy and deter patrons from making reservations. In contrast, other landowners planning resort areas have even expressed an interest in renewable energy projects on their property as part of diversified land use planning. In some areas, renewable energy projects have been viewed as tourist *attractions*.

Because of the concerns of private landowners, state or federal lands are particularly attractive as potential energy project sites. Although these lands generally require more permitting for project development, lower lease rates may make these lands more favorable than private lands.

UTILITY ACCESS AND IMPACT

Access to utility transmission lines was the primary factor considered in project identification relating to utilities. Because it is possible to upgrade or build new lines to support projects, sites were not necessarily eliminated due to limited transmission access or distance from transmission lines. In some cases, however, it became obvious that the expense and/or distance of new transmission lines was excessive and these projects were dropped from further consideration.

Appendix C includes more specific information on the Hawaiian utilities, including transmission and distribution maps, expansion plans, and diurnal and seasonal load characteristics.

In addition to electrical access, solar thermal projects require a method of disposing of a certain amount of waste water. Biomass conversion technologies have considerably more waste removal requirements than other renewable energy technologies; however, in many instances the "waste" byproducts may be desirable for agricultural uses and can be sold to various plantations, thus eliminating the need for utility waste removal.

ENVIRONMENTAL AND CULTURAL SENSITIVITY

All project sites were screened for the preexistence of biologically significant native ecosystems or rare species, as well as the existence of culturally valuable archaeological sites, and the ability to mitigate against disturbances in areas that were found to be sensitive. While this screening was conducted by persons closely associated with the Nature Conservancy and familiar with the Hawaiian islands, it does not preclude the possibility that some biological or cultural feature may have been overlooked. Any site for proposed development in the state of Hawaii should be carefully surveyed and evaluated before proposed construction.

In this study, the environmental and cultural sensitivity of a potential project site was used to rank the projects. In most cases with environmental or cultural conflicts, possible resolution can be obtained by restricting the project size or using appropriate siting practices.

For the environmental screening, information regarding rare and endangered species was acquired from various sources, including the Hawaii Environmental Risk Ranking Project's Risks to Ecosystems Report, the Nature Conservancy's Hawaii Heritage Program, U.S. Fish and Wildlife Service Hawaiian Waterbird Recovery Plan, the Hawaii Stream Assessment, and personal communications with scientists and land managers in Hawaii.

For the purposes of this report, cultural resources include prehistoric, historic, and modern elements. In Hawaii, prehistoric resources generally refer to those prior to the arrival of Captain James Cook in 1778. Elements of historic, or post-contact, resources include sites listed on the State of National Register of Historic Places, historic districts, fishponds, and a variety of site types studied by the Historic Preservation Division under the Department of Land and Natural Resources. The Historic Preservation Division provided broad scale information on historic and archaeological data. Since the 1970s, archaeological surveys have been included for developments due to the Historic Preservation Law. Information from these surveys, as well as information from the University of Hawaii and Bishop Museum projects, was also incorporated into the report to the extent possible. Appendix D contains an environmental and cultural rating for each of the proposed project sites.

PUBLIC ACCEPTANCE

The assessment of public acceptance is critical in all modern development projects as public opposition to development puts significant investments at risk. While it was not appropriate in this preliminary stage to address the public at large about concerns relating to the development of specific renewable energy projects, during site visits, every attempt was made to identify areas of concern at the local level. This was accomplished through interviews with landowners, public planning officials, and past experience from renewable energy developers in Hawaii. Specific areas of concern are addressed in the following discussion of project sites.

RENEWABLE ENERGY PROJECT LISTS FOR THE STATE OF HAWAII

Following the completion of the above screening processes, project lists were developed for each technology. In the following sections, the project lists are presented by island. An overall map that identifies the general location of the potential project sites is provided for each island. A brief discussion of each project site by resource type follows. Site-specific maps are included in Appendixes E through J. Note that the majority of the site-specific maps identify representative, not exact, locations for projects and are provided for general information only. Exact project siting will require negotiations with the landowner and detailed resource assessment. Although in some cases, the landowner has identified a specific parcel for development, the majority of the landowners have only agreed to consider the possibility of a project and have not agreed to the specific sites located on the maps. The location of biomass energy crop projects are based on mill site locations, although the land area of the projects would extend well beyond the mill site location.

For the sake of completeness, small-scale applications are listed on each of the project lists for wind and solar. There are a number of small-scale, demand-side or small-scale, dispersed-generation projects utilizing wind and solar energy that are suitable for wide-spread use in Hawaii; however, identifying specific sites for these applications is beyond the scope of this work. In future phases of this program, the economics for these types of systems will be evaluated for representative locations that could be replicated throughout the islands. The lack of detailed discussion of these applications should not diminish their potential value. Small-scale, demand-side or small-scale, dispersed-generation projects utilizing solar and wind include applications such as solar hot water heating, solar or wind for off-grid remote applications, wind water pumping, distributed photovoltaics to defer utility upgrades, and solar desalination.

HAWAII

There is abundant available land on the island of Hawaii suitable for renewable energy development projects. Vast areas with sufficient resources for development were identified after the screening process. The value of renewable energy projects is more limited by the size of the utility load than by any other factor. The peak annual load in 1992 was 150 megawatts. Due to the large amount of available land, and the low apparent demand, only a limited number of possible projects were chosen for discussion and they do not necessarily represent the island's maximum potential. In addition, broader regions were identified for project sites rather than specific locations and a number of potential projects may be possible within a given region. The projects that are presented, however, are representative of the types of projects that are available to develop in Hawaii and it is anticipated that additional projects that may be proposed would have similar characteristics. Potential renewable energy projects for each technology are discussed in the following section. The general locations of potential project sites are shown in Figure 1.

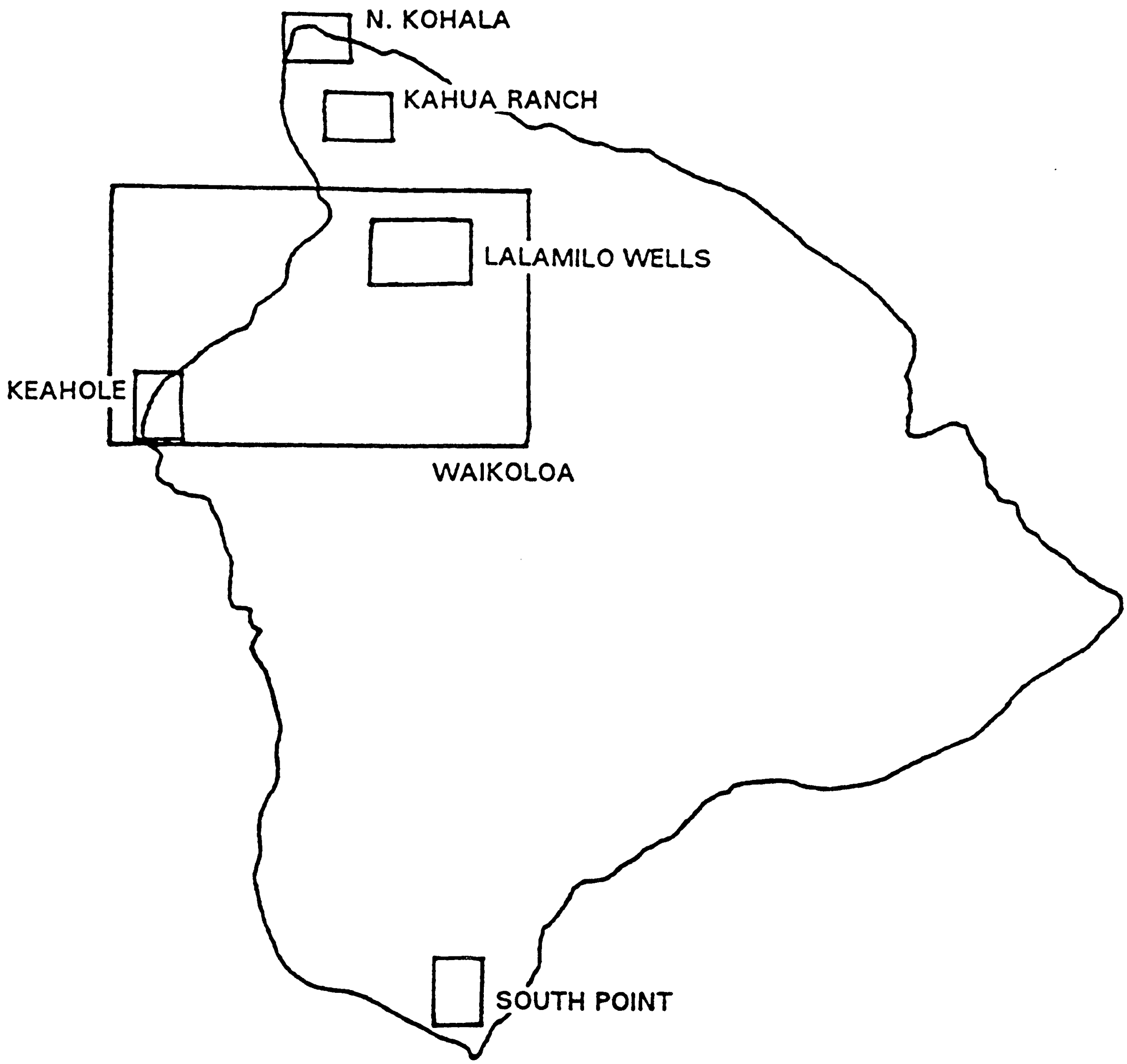

Figure 1. Hawaii Project Sites

WIND

On Hawaii, Mauna Loa and Mauna Kea, the two tall volcanoes on the island, represent significant barriers to the trade winds. As a result, the wind on this island is diverted to the north of Mauna Kea and accelerated through the Waimea saddle and over the Kohala Mountains, producing a several areas of significant wind resource. To the south of Mauna Loa, the diversion of the wind produces a smaller area of significant wind resource at the southern point of the island. Potential projects were identified as shown in Table 1.

Table 1. Hawaii Wind Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
HAWAII	WIND	W1	LALAMILO WELLS
HAWAII	WIND	W2	NORTH KOHALA
HAWAII	WIND	W3	KAHUA RANCH
HAWAII	WIND	W4	SOUTH POINT
HAWAII	WIND	N/A	SMALL-SCALE APPLICATIONS

W1: Lalamilo Wells. Located in the plains between Kohala and Mauna Kea, the Lalamilo Wells area is the site of an existing 2.3 MW wind farm made up of 39 Jacobs 17 kW and 81 Jacobs 20 kW wind turbines. There are no publicly available resource data at this site; however, a number of wind energy developers have monitored the area and have proposed projects, which testifies to its value as a potential project site. The land is zoned for agriculture and currently used primarily for grazing. It is owned by the state and a portion of the land has been leased to the County of Hawaii Department of Water Supply for wells. (The County currently purchases the energy from the wind farm.) The terrain is gently sloping and poses no problems for development or operation. The existing transmission line limits additional development to less than 3 MW; however, an upgrade to the line, or a new line could be installed for a project without severely penalizing the economics of a potential project. Another benefit to this project location is that it is centrally located in the area of the island projected for the fastest load growth in the future and generation projects on this side of the island are desirable for the utility. In addition, because the water department is satisfied with their existing contract to purchase the wind energy, the possibility of selling energy to a third party exists in this area. No major conflict is expected with biological resources and the existing wind farm is not visible from any tourist areas. Some of this area has been targeted by the Division of Historic Preservation for preservation because it is part of the early Hawaiian Waimea field system and remnants of agricultural terracing and habitation are abundant. At a minimum, replacement of the existing wind farm should be permitted. In addition, neighboring landowners such as Parker Ranch, are open to consideration of a wind energy project. A map of one potential location for a project in this vicinity is provided in Appendix E.

W2: North Kohala. The North Kohala area has long been considered to have good wind resources despite a lack of high-quality data. This area is owned by Chalon International and their current land use plan has set aside land parcels for renewable energy development. This land is currently zoned for agriculture. Other planned development in the area includes tourist resorts, housing, and golf courses. The Department of Water Supply has also identified this area as the most likely location for the near-term installation of additional water wells to support the anticipated growth in the Kona and Waikoloa areas. Although there is limited utility access at this time, the development of these other projects will require an additional transmission line. The proposed site is located in the lowland area of North Kohala, away from significant biological resources. A Marine Conservation District, Lapakahu State Park, is located on the coast but should not be affected by the proposed project. There are cultural sites in the vicinity, including King Kamehameha's birthplace, but no conflict is foreseen. Because of the resource and transmission uncertainty, this project is ranked below Lalamilo Wells. Appendix E provides a map that shows the land parcels which have been set aside for renewable energy development.

W3: Kahua Ranch. Located on the Kohala ridge line, Kahua Ranch is also the site of a small existing wind farm. A larger wind farm was recently removed due to the poor reliability of the equipment. The area has been shown to exhibit exceptional wind resources. The terrain consists of rolling hills and the location of the previous wind turbines is situated between two cinder cones. Kahua Ranch is a diversified ranch that includes carnation growing, grazing, and wind energy. The potential project site is currently used for grazing. The land is zoned for agriculture; however, the state has proposed re-zoning to conservation because of biological resources. The landowner is a long-time advocate of wind energy and has argued against the re-zoning on the basis that the land has long been used for grazing. The existing transmission is limited to approximately 5 MW; however, an upgrade to this line has been discussed by the utility primarily to service proposed tourist development and water pumping wells at the end of the peninsula. It is unclear at this time who will pay for this transmission line upgrade. Public acceptance is not considered to be a problem in this area. Although this site has excellent resources and strong interest by the landowner, it is ranked below the North Kohala site because of the potential for re-zoning. A map of the site is provided in Appendix E.

W4: South Point. The South Point area is the location of the existing Kamaoa wind farm on land owned by the Bishop Estate and zoned for agriculture. Non-public data have also been collected on nearby property belonging to the Campbell Estate. The wind resource in this area is significant and the terrain is relatively flat. The power generation potential at South Point is substantial; however, the main transmission line into which the Kamaoa wind farm is connected is planned for use in delivering power from the geothermal power plant in the east (Puna area) to the loads in west Hawaii, which leaves no surplus transmission capacity. There are no transmission upgrades planned for this line, so further projects at South Point are unlikely unless the power can be used on location. There is little anticipated load growth in this area. An additional complication for this area is the significant amount of cultural and biological resources. Hawaiian Homes owns the land to the south of the existing wind farm and they have indicated that they would not consider any additional development under any circumstances. As a result of these factors, additional wind energy development at South Point is not likely to occur before the previously discussed projects on Hawaii. A map of the South Point area showing the location of the existing project is provided in Appendix E.

SOLAR

Solar resources for Hawaii are concentrated on the western side of the island. The potential project sites for large-scale solar applications are presented in Table 2 and discussed below. Other areas that were considered and eliminated included South Point (limited transmission and environmental conflicts), Kau Desert (competing land use), and the Humuula saddle (endangered species, volcanic hazards).

Table 2. Hawaii Solar Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
HAWAII	SOLAR	S1	WAIKOLOA
HAWAII	SOLAR	S2	KEAHOLE POINT
HAWAII	SOLAR	S3	NORTH KOHALA
HAWAII	SOLAR	N/A	SMALL-SCALE APPLICATIONS

S1: Waikoloa. This broad regions includes the Waikoloa general vicinity from Lanuipuaa to Kawaihae along the coast and inland toward Waimea. The better sites are towards the coast; however, significant tourist development on the coast may make inland sites more feasible. There is an excellent solar resource in the entire area that has been documented by a number of data sources, including both global and direct radiation data. Land zoning is a mixture of agriculture, urban, and conservation. The terrain is relatively flat near the coast with slopes as great as 5% further inland. A map showing the Waikoloa area is provided in Appendix E. An exact project site has not been identified because there are numerous large parcels of undeveloped land that would be suitable for development in this area. There are numerous landowners in this vicinity including the Parker Ranch, Transcontinental Development Corporation, and the State. New generation on this side of the island is desirable due to the significant load growth. HELCO is planning generation additions in this area and there are several 69 kV transmission lines and substations within the general area. From a transmission standpoint, this area is currently the most desirable location on the island to add capacity. The Waikoloa area is well known for abundance of rare anchialine pools; however, it should be possible biological conflicts to avoid through siting. There are a number of cultural sites on the makai side of the highway. These can also be avoided through appropriate siting.

S2: Keahole Point. This area is north of Kona and south of the Waikoloa area. The Natural Energy Laboratory of Hawaii (NELH) is located in the Keahole Point Area. There is a long period of record of measured global horizontal and diffuse horizontal solar radiation data maintained by the NELH that indicates that the direct insolation is 13% higher than at Manoa. There is land zoned urban in the vicinity of NELH and surrounding land is zoned conservation. The majority of the land is owned by the State. In the immediate vicinity, possible competing uses for the land include the expansion of the Kona airport, additional development at NELH, or the leasing of the land near NELH for aquaculture tenants. Should these potential developments occur, however, there is additional land in the broader area that is likely to be available. The terrain is fairly level and suited to all types of solar development. However, land grading and development costs can be high in this area and this may affect project siting and costs. An additional benefit for solar trough technology is that NELH has the ability to provide sea water for cooling. There are existing transmission lines in the vicinity and, as previously, discussed, generation on this side of the island is desirable. No biological or cultural conflicts are foreseen. A map of the area with one potential project site identified is provided in Appendix E.

S3: North Kohala. North Kohala area is thought to have the highest insolation of the three solar sites considered on Hawaii. Its steep slope makes it undevelopable for parabolic trough systems, but parabolic dish concentrating systems or photovoltaics are possible. As discussed for wind energy projects, Chalon International, one of the landowners in this area, has set aside parcels of land for renewable energy development. Other landowners include Kohala Ranch, the Queen's medical center, Parker Ranch, the State, and Hawaiian Homes. At present, the 69 kV transmission line ends at the Kohala Ranch substation, about 8 miles south of Mahukona. However, additional load growth at the northern end of the peninsula is planned and a transmission line brought in to serve this load could be used for any renewable energy project. Although biological and cultural resources exist, conflict should be avoidable through appropriate siting. A map of the parcels set aside for renewable development is provided in Appendix E.

BIOMASS

Potential biomass projects are classified into two categories based on the source of the biomass: energy crops and organic waste. Future work will further categorize projects based on the conversion technology that is utilized and the end energy product, either transportation fuels or electricity. For Phase 1, potential projects mean (1) that there is an area of land available and suitable for the production of a biomass energy crop or (2) that there are available and potentially collectable organic waste products not currently being converted into an energy end-product. Because the processing facilities were generally assumed to be located at existing mill sites, it was also assumed that transmission lines to the sites were adequate. However, in many cases new processing facilities or modifications may be required for biomass crops other than sugarcane. Similarly, because of the existing agricultural use of the land, environmental and cultural conflicts or public opposition are not likely to develop based on changing the type of crop at the site or using existing processing facilities. Table 3 summarizes the characteristics of the potential biomass projects identified for Hawaii. These projects are discussed in more detail below. Maps showing the location of the proposed energy crop projects for various species are included in Appendix J.

B1: Paaukau. One of the most likely energy crop projects in the state is the use of these lands that were previously used for sugar by Hamakua Sugar Co. Because of Hamakua's recent bankruptcy, the land will be available for other crop considerations, and, as such, it is the highest ranking biomass project on

Hawaii. The climate and soil conditions are particularly good for tree crops; however, grass crops were also considered at this site. Due to the bankruptcy, ownership and future plans are unclear at this time.

Table 3. Hawaii Biomass Projects

TREE CROPS

LOCATION	COMPANY	ACRES CONSIDERED	PRODUCTIVITY RANGE (DRY/TON/AC/YR)	ACRES	ANNUAL PRODUCTION (DRY TON/YR)
PAAUKAU	HAMAKUA SUGAR CO.	41,794	13-18	5,671	87,010
			11-13	1,132	13,510
			8-11	4,631	43,040
PEPEEKEO	MAUNA KEA AGRIBUSINESS CO.	32,246	13-18	37	560
			11-13	5,995	68,240
			8-11	13,042	124,990
PAHALA	KA'U AGRIBUSINESS CO.	20,007	13-18	1,831	32,670
			11-13	0	0
			8-11	358	3,240

GRASS CROPS

LOCATION	COMPANY	CANELAND ACRES	ACRES HARVESTED	PRODUCTION (DRY TON)	ANNUAL PRODUCTION (DRY TON/AC/YR)
PAAUKAU	HAMAKUA SUGAR CO.	27,837	7,586	190,790	12.6
PEPEEKO	MAUNA KEA AGRIBUSINESS CO.	14,683	5,793	120,740	10.4
PAHALA	KA'U AGRIBUSINESS CO.	12,559	4,374	123,180	14.1

NOTE: GRASS PRODUCTION ESTIMATES BASED ON ACTUAL SUGARCANE HARVESTS, BIOMASS TO ENERGY CROP CHOICE WOULD LIKELY BE CUSTOM SUITED TO THE APPLICATION. SHORT ROTATION GRASS CROPS OTHER THAN SUGARCANE MAY BE VIABLE ALTERNATIVES.

ORGANIC WASTES

REGION	GEOGRAPHIC AREA	ORGANIC WASTE (DRY TON/YEAR)	PRIMARY COMPONENTS
REGION G & H	NORTHWEST SIDE OF THE ISLAND	71,550	95% OF TOTAL IS DAIRY, GREEN, & FOODWASTE
REGION I	NORTHEAST CORNER OF THE ISLAND	124,480	UNKNOWN

B2: Pepeeko. This area, also considered for both tree and grass crops, also has particularly favorable climatic and soil conditions for a tree crop. The landowner, C. Brewer and Co., Ltd., is interested in developing 7,000 acres for a tree project to make particle board.

B3: Pahala. The third energy crop project considered, Pahala, is owned by Ka'u Agribusiness Co. (C. Brewer and Co., Ltd.). This is the least productive tree crop land, but the most productive sugar crop land on Hawaii. Although this area has significant potential, it is ranked third because it is currently a productive facility and not presently under consideration for an energy crop.

Organic Waste. There are two plausible areas with enough resource of organic waste to support organic waste processing facilities on the big island, one in the west and one in the east. Regions G and H comprise the western coastal areas from South Kona to Kohala. Regions I and J comprise the northeastern area of the island from greater Hilo to the Hamakua Forest.

HYDRO

There are a significant number of small hydro facilities operating on Hawaii and a new 10 MW project was recently put on-line. The hydro resource on this island is concentrated in the Kohala area and the Hamakua coast. Upgrading some of the existing or abandoned facilities and ditch systems has been evaluated by HELCO and others; however, at this time, additional upgrades were determined not to be feasible above those either recently completed or in process. A hydro project on Hawaii on the Honolii Stream was denied a permit in the late 1980s due to concerns over potential effects on surfing conditions and aquatic life. Although resource potential exists on this stream, it is not considered to have development potential because of the denied permit. Several new potential hydro projects were recently proposed by the same company that developed the new 10 MW project in the Hamakua coast area. Although they are expected to face public opposition, they are presented below as potential projects and summarized in Table 4.

Table 4. Hawaii Hydro Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
HAWAII	HYDRO	H1	UMAUMA
HAWAII	HYDRO	H2	KAWAINUI
HAWAII	HYDRO	H3	KOHOLAELE, LUAHALA, KAULA

H1: Umauma. The Umauma Stream is located on the Hamakua coast and drains just north of Hakalau. It is anticipated that a project of approximately 15 MW could be installed at this location. This project has not been previously proposed and because of its size and because public acceptance is anticipated to be more likely at this location than other proposed projects, it is the most likely of the hydro projects on Hawaii to be developed.

H2: Kawainui. The Kawainui Stream is also located on the Hamakua coast south of the Umauma project. It is anticipated that a project of approximately 6 MW could be installed at this location. This project has not been previously proposed.

H3: Koholaele, Lauhala, Kaula. These three potential projects are located on the Hamakua coast and they drain between the towns of Paauilo and Ookala. They are less likely to be developed than the two previously discussed on Hawaii because, in order to be developed, it will be necessary to reach an agreement with parties that use the water for irrigation.

WAVE, OTEC, AND GEOTHERMAL

No specific wave energy projects were identified on the island of Hawaiiin this phase of the project. Additional investigation of this technology will be considered in future phases of this work. A single project site was chosen for further analysis of OTEC systems at Keahole Point (Table 5). The project site was chosen based on the existing location of the HayaiiNatural Energy Laboratory, which is the site of a currently operating experimental OTEC facility. The area is zoned urban and the site was chosen because of its proximity to deep ocean waters that are a requirement for OTEC technology. The geographical features and existing installed equipment make it a natural choice for further expanded efforts to bring OTEC to the reality of utility-scale power generation. A single project site was also chosen for geothermal power development, the Kilauea east rift zone. It is assumed that the potential sites will be chosen in areas of gentle to moderate terrain.

For OTEC, additional resource areas for the deployment of the technology have been identified off the Puna coast on the eastern side of Hawaii and near South Point. Transmission constraints and environmental and cultural conflicts are likely to prevent development near South Point. The northeast coastline of the island has also been identified as having significant wave energy resources. Due to the protected nature and limited transmission access on the northern portion of this coastline, potential development is likely to be more suitable for the Hilo area, despite the lower resource.

Table 5. Hawaii Wave and OTEC Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
HAWAII	OTEC	O1	KEAHOLE POINT
HAWAII	GEOTHERMAL	G1	KILAUEA EAST RIFT ZONE

MAUI

The land availability screening process eliminated the vast majority of Maui's land from consideration; however, on the limited amount of suitable land, a number of potential renewable energy projects that appear to have significant development potential were identified. The mountain regions of Maui are zoned conservation and are largely national park and forest reserve lands. These and most other conservation lands are inaccessible for energy project development. The south side of Haleakala to the coast and the northeast side of the West Maui Mountains were eliminated due to terrain constraints and lack of utility access. The majority of Maui's remaining coastline is developed for tourism. Potential renewable energy projects are discussed for each technology in the following section. The general locations of potential project sites are shown in Figure 2.

WIND

The primary wind resource on Maui lies in the central valley where the trade winds accelerate between the barriers of Haleakala and the West Maui mountains. Wind potential also exists in the north western slope of the West Maui Mountains and of lower Haleakala. A number of wind energy project sites with significant development potential are summarized in Table 6 and discussed below.

Table 6. Maui Wind Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
MAUI	WIND	W1	WEST MAUI
MAUI	WIND	W2	MCGREGOR POINT
MAUI	WIND	W3	PUUNENE
MAUI	WIND	W4	NW HALEAKALA
MAUI	WIND	N/A	SMALL-SCALE APPLICATIONS

W1: West Maui. Zond Systems, a wind energy developer, has negotiated a lease with the landowner, Maui Land and Pineapple, for a 10 MW wind energy project in this area. Although there is additional land in this area that may be suitable for wind energy, the landowner is reluctant to consider any additional leases for wind energy because of existing and planned tourist development. In fact, Zond's original project site was moved further inland because the landowner was concerned about its proximity to a planned golf course. Expansion may be possible in the future if the first 10 MW project proves to have little affect on other planned land uses. The land is zoned for agriculture and is currently used for grazing. The terrain is fairly complex; however, no problems are anticipated with construction or maintenance. Other land in the area is zoned for conservation (part of the West Maui Forest Reserve). Transmission lines from the northwestern slope of west Maui have remaining capacity to accommodate a project of up to 20 MW. Despite the landowner's concerns, the project is unlikely to be noticeable from the coastline developments and little public opposition is anticipated. Although this area of Maui is rich in biological resources and many cultural sites are known to exist here, a correctly sited development is likely to have little environmental impact. The map of the approximate project location is provided in Appendix F.

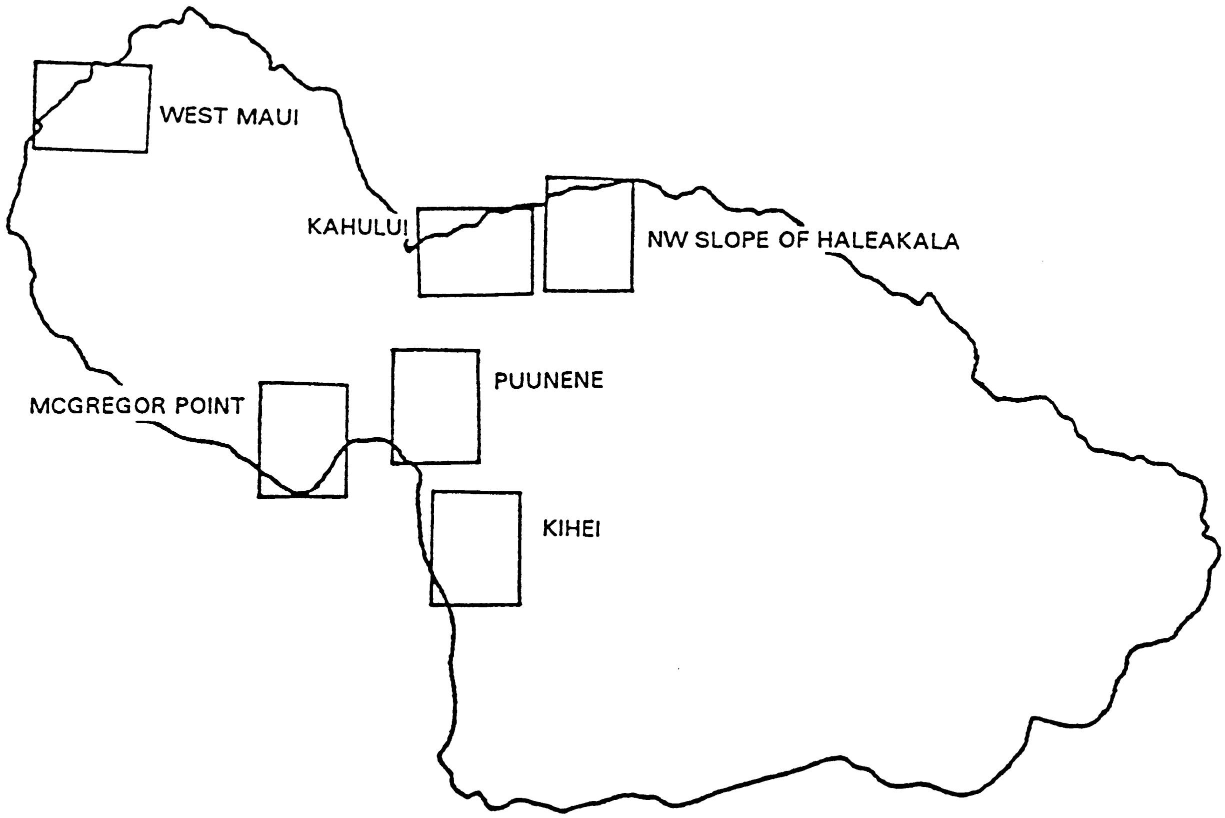

Figure 2. Maui Project Sites

W2: McGregor Point. The highest average wind speed recorded on Maui is at the southwestern corner of the isthmus at McGregor Point. The coastal lands in that area are not available for consideration of energy projects; however, the land rising up, away from the water is zoned resource and general conservation land and could be developed for a wind energy project. The land is owned by the state and currently leased for grazing. This location is close to Maui Electric's Maalaea generating stations and there is available transmission capacity and land for a project of at least 10 MW in size. The terrain is also fairly complex; however, no problems are anticipated with construction and maintenance. In fact, Maui Electric recently constructed a transmission line over the ridge line under consideration and a potential wind project would likely be located near this line. There are no known biological or cultural resources in the vicinity that would be impacted by a wind energy project. The project would, however, be highly visible from the main road from the airport to the tourist developments in West Maui. For this reason, it is ranked lower than the West Maui project. The higher on the ridge the project is installed, the less visible it will be. A map of the approximate project location is provided in Appendix F.

W3: Puunene. The old airport site near Puunene is located in the center of the Maui isthmus approximately four miles south of Kahului on land that is zoned for agriculture. The actual level of wind resource available at this site is uncertain, although its location suggests that there is significant potential. This land is also owned by the state and the majority of the land is currently planted in sugar cane. The state, along with Maui County, is currently developing a master plan for the 1000 acre site. Due to its central location, the state is considering several potential uses for the land, including a waste water treatment plant, light industry, and tourist activities. In addition, the state would like to maintain some agricultural land in this area to serve as a buffer between Kahului and the tourist developments in Kihei.

Despite these other considerations, it appears that sufficient land may still be available for a wind energy project. The land is flat and there are sufficient existing transmission lines in the vicinity to support a 10 MW project. In addition to the 23 kV transmission line and substation adjacent to the site, it is likely that transmission improvements will be incorporated into the master plan for the site. There is no foreseeable conflict regarding environmental or cultural sensitivity. Due to its location, the project will be fairly visible. For this reason and because of possible conflicts with other plans for the land and uncertainty regarding the resource, it is ranked lower than the first two projects. A map showing the state-owned land is provided in Appendix F.

W4: NW Slope of Haleakala. The northwestern side of Haleakala represents vast expanses of windy land zoned for agriculture and planted in sugar. The terrain is gently sloped and would offer no particular challenges for construction or operation of a wind energy project. The major landowner in this area, HC&S, is a large power consumer and would consider a wind energy project if it proved to be more economical than the existing land use. Note, however, that HC&S is one of the most profitable sugar producers in Hawaii and not likely to remove productive lands from sugar in the near future. For this reason, this project received the lowest ranking of the Maui wind energy projects. Nonetheless, the potential exists for a suitably sited project, perhaps on less productive land, and there is flexibility in locating an exact project site. Existing transmission lines to this area are sufficient for a project of approximately 10 MW. There are no foreseeable environmental or cultural concerns in this area. The project will not be visible to the majority of the island residents or tourists. A map showing the general area and one of many potential project locations is provided in Appendix F.

SOLAR

Maui's solar resources are concentrated on the leeward side of the island and in the central isthmus. Land with solar resources often conflicts with tourist developments. The potential project sites, shown in Table 7, were identified for large-scale solar energy applications and are discussed below. Additional areas that were considered and were eliminated included the Lahaina area due to competing uses and the tourist nature of the area.

Table 7. Maui Solar Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
MAUI	SOLAR	S1	PUUNENE
MAUI	SOLAR	S2	KIHEI
MAUI	SOLAR	S3	KAHULUI AIRPORT
MAUI	SOLAR	N/A	SMALL-SCALE APPLICATIONS

S1: Puunene. This site is the same as identified above for wind energy. There is existing global radiation data that indicate a significant resource, although there are no direct data available. A solar trough project may be feasible for this site and it may integrate well with the proposed waste-water treatment facility by providing the option of waste water effluent re-use for power plant cooling purposes. The site is also suitable for other solar technologies, including photovoltaic and solar dishes. As discussed above, the terrain and soil conditions are suitable for development, there are no cultural or environmental constraints, and there is existing transmission line in the vicinity. A solar project would be less visible than a wind project at this site; however, a solar project would occupy more land. In conjunction with the development of a waste-water treatment plant, little public opposition is anticipated. A map of the site is provided in Appendix F.

S2: Kihei. This area includes the lower southwestern slopes of Haleakala, above the tourist developments of Kihei, including the Research & Technology Center which is the location of the

PVUSA site. The solar resource in this area is generally considered to be better than at Puunene, but there are also no direct radiation data available. Because of the tourist development along the coast and the growth anticipated for this region, any project development would likely be above the developed coastal band of land. The largest landowner in this area is Haleakala Ranch and they are willing to consider the use of their land for a solar energy project. The majority of the land is zoned for agriculture and used for grazing. The terrain has a much greater slope than Puunene (3-6% at best increasing to 10% or more to the south and further inland) and the soil conditions are less favorable. As a result, development of a project with solar trough technology may be more difficult than photovoltaic or solar dish technology and it is considered to be a slightly less desirable location than Puunene. There are transmission lines in the vicinity and, due to the projected load growth, this is a desirable location for new generating capacity additions. Although there are known biological resources in this general area, they are scattered. As a result, environmental conflicts should be avoidable by appropriate siting. A map of the general area and one potential project site is provided in Appendix F.

S3: Kahului Airport. This site covers the area to the south and east of the Kahului airport. The land is currently planted in sugar and zoned for agriculture. The majority of the land is owned by Alexander and Baldwin Sugar Co., Inc. Reported high winds in this area may indicate a difficulty in developing solar concentrating projects, which depend on focus for high efficiency. Replacing the sugar land with a solar project is unlikely unless it proved to be significantly more economical than the current use. The land is relatively flat and suitable for all types of solar development. There are existing transmission lines in the vicinity due to the proximity of the Kahului power plant. There are no known environmental or cultural impacts. Due to competing uses in the present as well as the future, this site is ranked below the first two. A map showing the general area and one potential project site is provided in Appendix F.

BIOMASS

Table 8 summarizes the anticipated production for the biomass projects identified on Maui and they are discussed in more detail below. Maps showing the location of the proposed energy crop projects for various species are included in Appendix J.

B1: Paia. These lands are owned by HC&S and are currently planted in sugar. Approximately 12,000 hectares were considered for use, with a processing facility located at the site of the existing mill. Of the three energy crops considered on Maui, the Paia project has the highest production per hectare for tree crops. At present, the long-term plans for this land are to continue sugar cultivation. As previously discussed, any replacement of sugar would have to show a significant economic benefit in order to be considered by the landowner. A portion of this land was also considered suitable for grass crops. It receives the highest ranking for a biomass energy crop project on Maui because of its high productivity.

B2: Puunene. Approximately 23,500 acres, also owned by HC&S and planted in sugar, were considered for use in the Puunene area. The same comments for the Paia site apply to Puunene. Because both the Paia and Puunene projects are owned by HC&S, they were considered together for grass crops.

B3: Lahaina. The third energy crop project considered for Maui is located on land owned by Pioneer Mill Co., Ltd. Although this project was also considered to be suitable for both tree crops and grass crops, it receives a lower ranking because the land is situated in a location in which a number of other potential uses would compete with a potential energy crop should this land go out of sugar production.

Table 8. Maui Biomass Projects

TREE CROPS

LOCATION	COMPANY	ACRES CONSIDERED	PRODUCTIVITY RANGE (DRY/TON/AC/YR)	ACRES	ANNUAL PRODUCTION (DRY TON/YR)
PAIA	HAWAIIAN COMMERCIAL & SUGAR CO.	29,516	13-18	2,174	34,690
			11-13	2,693	31,200
			8-11	6,686	61,850
PUUNENE	HAWAIIAN COMMERCIAL & SUGAR CO.	23,291	13-18	0	0
			11-13	1,159	13,150
			8-11	9,078	82,300
LAHAINA	PIONEER MILL CO.	15,283	13-18	17	240
			11-13	1,265	14,520
			8-11	3,726	35,290

GRASS CROPS

LOCATION	COMPANY	CANELAND ACRES	ACRES HARVESTED	PRODUCTION (DRY TON)	ANNUAL PRODUCTION (DRY TON/AC/YR)
PAIA/PUUNENE	HAWAIIAN COMMERCIAL & SUGAR CO.	35,857	17,340	519,030	15.0
LAHAINA	PIONEER MILL CO.	6,648	2,013	62,810	15.6

NOTE: GRASS PRODUCTION ESTIMATES BASED ON ACTUAL SUGARCANE HARVESTS, BIOMASS TO ENERGY CROP CHOICE WOULD LIKELY BE CUSTOM SUITED TO THE APPLICATION.

Organic Waste. All regions of Maui, with the exception of the eastern portions of Haleakala (which are dominated by the National Park and several forest reserves), can be combined to merit the siting of a single waste-to-energy facility in central Maui. Much of the waste from these regions is currently hauled to a central landfill so there are no real additional transportation costs to be associated with transportation for an organic waste conversion facility on Maui.

HYDRO

There are currently several small hydro facilities operating in Maui. Evaluation of these facilities did not indicate that any substantial upgrades were feasible above those either recently completed or in process. Only one potential new hydro project (summarized in Table 9) was identified on Maui that appeared to have some development potential and it is discussed in more detail below. As previously discussed, all hydro projects are expected to face strong public opposition.

Table 9. Maui Hydro Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
MAUI	HYDRO	H1	WAILUA IKI

H1: Wailua Iki. Located on the northeastern region of Maui, a hydro project was proposed for this area by Bonneville Pacific in the 1980s, and it was strongly opposed for environmental reasons. It is anticipated that a project of approximately 3 MW could be installed at this location. Although opposition to a potential project in this area is still likely, it may be more acceptable than the majority of other potential hydro locations in the state.

WAVE AND OTEC

No specific project sites for either wave or ocean thermal on Maui were identified in this phase of the project. Previous work on the siting of OTEC projects, conducted by PICHTR, indicate that there is sufficient resource (i.e., appropriate bathymetry) for two to three floating OTEC plants off the northeast coast of Maui near Hana. The scenic beauty and protected resources of this area will likely result in significant public opposition to any land-based systems. For wave energy, the resource on Maui is concentrated on the northeastern coastline. Outside of the urban area surrounding Kahului, it is anticipated that a wave energy project would face public opposition. In addition, transmission access is limited.

MOLOKAI AND LANAI

Molokai and Lanai are both small in relation to the other Hawaiian islands and are relatively low in population density as well as the size of the island utilities. Large areas with development potential for renewable energy projects were determined to exist on each island following the land availability screening process; however, there is insufficient demand to justify a large-scale project. In addition, due to the small size of the utilities, very little intermittent power generation is likely to be valuable. Renewable energy projects on these islands can be more appropriately incorporated through demand-side (i.e., solar hot water heaters) or small-scale, dispersed generation projects (i.e., water pumping). However, because both islands exhibit significant renewable energy resources, potential utility-scale projects are discussed here on a limited basis. The utility-scale projects identified for these islands are more likely to be valuable in the event that the island populations grow, or the island utilities become interconnected. Potential projects are discussed in the following sections for each technology. The general locations of potential project sites are shown in Figure 3.

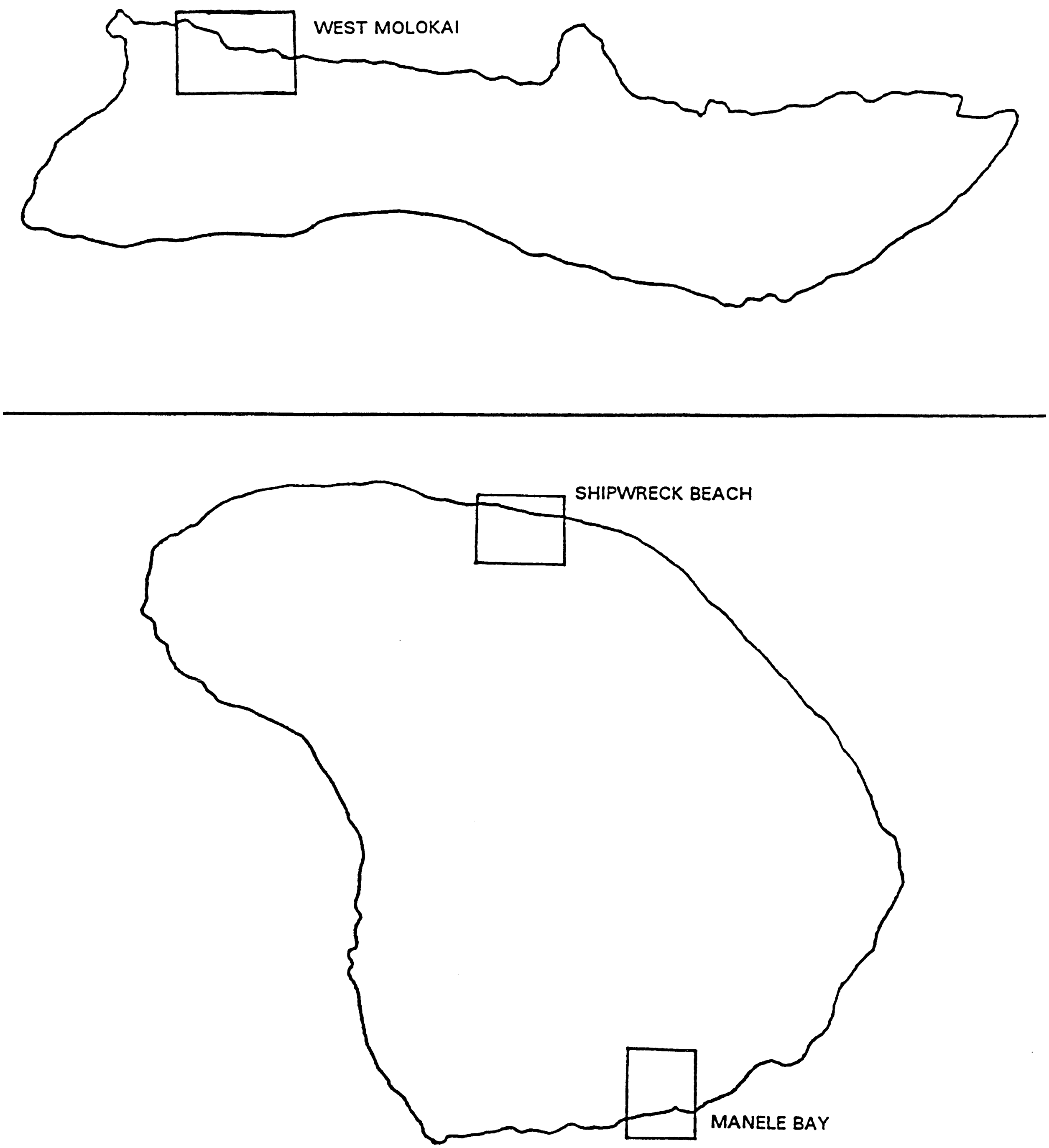

Figure 3. Molokai and Lanai Project Sites

WIND

Molokai is unique among the major Hawaiian islands in that it lies almost parallel to the prevailing trade winds. Exposed areas on most of the island are estimated to have significant wind resources with the most substantial wind resource being located in the northwestern corner. Lanai lies partly in the wind shadow of western Maui. Nevertheless, there appears to be some wind resource on the northwestern third of this island. Potential wind energy project sites for these islands are summarized in Table 10 and discussed below.

Table 10. Molokai and Lanai Wind Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
MOLOKAI	WIND	W1	WEST MOLOKAI
MOLOKAI	WIND	N/A	MISCELLANEOUS SMALL-SCALE APPLICATIONS
LANAI	WIND	W1	INLAND FROM SHIPWRECK BEACH
LANAI	WIND	N/A	MISCELLANEOUS SMALL-SCALE APPLICATIONS

W1: West Molokai. Eastern Molokai is largely zoned conservation and difficult to access; however, the wind resource of west Molokai is much more accessible and well documented. Most of the non-coastal lands of west Molokai are agricultural lands with acceptable zoning for wind energy development. There are no problems anticipated with potential development in this area with respect to terrain, landowner, or public acceptance. Environmental and cultural resources exist in this area; however, there is a large amount of land with significant wind resource available and with appropriate siting, conflicts should be avoidable. There is a small wind project currently operating in West Molokai. It is therefore unlikely, under current conditions, that any further development of intermittent energy resources will take place on this island in the near future other than small-scale projects. Small-scale projects are particularly suited to Molokai because of the cost of electricity to residential and commercial customers is high enough to make such ventures economical. Appendix G contains a map that shows the approximate location.

W1: Inland from Shipwreck Beach. The available wind resource on Lanai is uncertain. Contour maps of surface trade winds indicate an annual average surface wind speed approximately equivalent to that of west Maui. Limited by the small generating capacity of the utility, there is more than adequate land available to site a wind project on the non-coastal land above Shipwreck Beach. However, there are no existing transmission lines in this vicinity and projected load growth is on the opposite side of the island. As a result, it is unreasonable to consider wind energy as a potential generating source for Lanai unless demand increases significantly above its projected levels. Like Molokai, small-scale projects are particularly suited for Lanai because of high energy prices. Because the wind resource is located away from the energy demand areas on Lanai, only limited possibilities for wind, such as water pumping for livestock, are likely. Appendix G contains a map that shows the approximate location.

SOLAR

Solar resources for Molokai are concentrated on the western half of the island. On Lanai, the solar resources are concentrated on the southwestern portion of the island. Potential project sites for solar applications are listed in Table 11 and discussed below.

S1: West Molokai. With the exception of the rugged eastern portion of the island, good solar resources exist for most of Molokai. The best solar resource is on the southwest corner of the island; however, this area is not currently developed, and as such there are no load or transmission lines. Potential resort development in this area may change this situation. In the more populated areas of the island, small-scale applications are particularly well suited for Molokai because of the high cost of energy. As with wind, any utility-scale projects are not likely in the near future due to the limited utility size.

Table 11. Molokai and Lanai Solar Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
MOLOKAI	SOLAR	S1	WEST MOLOKAI
MOLOKAI	SOLAR	N/A	SMALL-SCALE APPLICATIONS
LANAI	SOLAR	S1	MANELE BAY
LANAI	SOLAR	N/A	SMALL-SCALE APPLICATIONS

S1: Manele Bay. For Lanai, a solar project is possible in the future in the southeastern region of the island near Manele Bay because demand in this area is likely to grow due to resort development and plans for luxury homes. However, if the demand grows to a sufficient level to support a commercial solar utility project, conflicting land uses and public acceptance may become a problem. There are significant opportunities in this area for small-scale applications, however, due to the abundant solar resource and the high cost of energy.

BIOMASS

Table 12 summarizes the characteristics of a potential biomass project for the island of Molokai. The project is discussed in more detail below. Maps showing the location of the proposed energy crop projects for various species are included in Appendix J. Biomass projects were not considered for Lanai. The organic waste generated on both Molokai and Lanai is not enough to merit the construction of a waste-to-energy plant on the island.

B1: Palaau. The available land area identified as suitable for biomass crop agricultural uses has been identified as capable of producing a mixed resource of both tree and grass crops. Relative to other biomass projects on other island, this project has relatively low productivity. A processing facility would likely be located in the Palaau area near existing generation and transmission lines.

Table 12. Molokai and Lanai Biomass Projects

TREE CROPS

LOCATION	REGION	ACRES CONSIDERED	PRODUCTIVITY RANGE (DRY/TON/AC/YR)	ACRES	ANNUAL PRODUCTION (DRY TON/YR)
PALAAU	CENTRAL AGRICULTURAL AREA	3,786	13-18	89	1,323
			11-13	54	673
			8-11	586	4,785

GRASS CROPS

LOCATION	REGION	TOTAL ACRES	ESTIMATED YIELD (DRY TON/AC/YR	PRODUCTION (DRY TON)
PALAAU	CENTRAL AGRICULTURAL AREA	5,500	18-24	99,000-132,000

HYDRO

No potential hydro projects were identified on Molokai at this time. Although resource potential exists on the Halawa Stream, the landowner has indicated that he is not interested in developing the resource or providing access.

WAVE AND OTEC

No project sites for either wave or ocean thermal on Molokai are recommended at this time for further analysis in this study. Previous work on the siting of OTEC projects, conducted by PICHTR, indicate that there is sufficient resource (i.e., appropriate bathymetry) for a small OTEC plant that could meet all water and power requirements on Molokai. For Lanai, it would be more cost effective to supply power from Maui via an underwater cable than to consider OTEC. The proposed Molokai OTEC site would be off the northern coast close to the Kalaupapa peninsula. Because of the proposed designation of this area for a National Park, any land-based facilities would have to be located in another area.

The wave energy resource for Molokai is also centered on the northern coastline. To the northeast of the Kalahulu peninsula, no development is considered to be permissible. To the northwest, it may be possible to site the land-based support for a wave energy project; however, for either wave or OTEC projects in this area, substantial transmission upgrades will be required.

OAHU

The land availability screening process eliminated the vast majority of Oahu's land from consideration. The island of Oahu contains the largest population of any of the Hawaiian islands and, as such, there are significant competing uses for any available land. Associated with its large population, tourist industry, and industrial sector, is by far, the largest island electrical utility system. Because of its large load, penetration of intermittent generating sources should not cause any problems. Even with a conservative assumption of 10% of peak load, the near-term practical penetration limit for intermittent technologies for the island is 128 MW of capacity, of which there are now approximately 13 MW installed. However, because of competition for land and protected natural features, it is much more difficult to identify available land for renewable energy projects on Oahu than on the other islands. As a result, the interpretation of the siting criteria was broadened for Oahu to allow consideration of a number of projects with unique features such as the location of projects on military lands. In addition, the potential for projects on land that is already or planning to be developed is considered (i.e., combining solar applications on rooftops with industrial development). These types of projects may also have applications on other islands; however, their evaluation on Oahu will be representative because site-specific features are not important considerations. Potential renewable energy projects are discussed in the following section for each technology. The general locations of potential project sites are shown in Figure 4.

WIND

On Oahu, the Koolau mountains and the Waianae Range enhance the trade winds. The northeastern (Kahuku), southeastern (Koko Head), and northwestern (Kaena Point) tips of Oahu have areas of substantial wind resource. The combination of land available for wind development and valuable wind resource is mostly concentrated in the Kahuku area. Although two other potential project areas are discussed, they are likely to have strict limitations on land use. Potential wind energy projects on Oahu are listed in Table 13 and described below.

W1: Kahuku Hills. Kahuku Hills is the location of an existing wind farm which at one time included fifteen 600 kW Westinghouse turbines and the 3.2 MW MOD-5B, a total of 12.2 MW of installed capacity. The existing transmission line has been shown to be capable of handling about 15 MW of installed wind capacity, leaving little room for expansion; however a new transmission line is planned for the late 1990s. Based on the existing plans, the new line could handle another 10-15 MW of installed wind capacity from the Kahuku area, either in the hills or on the flats nearer the ocean. There is sufficient land in this area for a much larger project, however, and an additional upgrade or a change in the current plans is possible. Potential wind energy projects as large as 100 MW have been proposed in the vicinity. The terrain is complex; however, no problems are anticipated with construction or operation. The land is owned by Campbell Estates and the land leased to the existing wind farm is also used as an army training ground. Although the landowner is not opposed to additional development, the U.S. Army has indicated that it is against additional development. As a result, there is a potential conflict on this land. Nonetheless, it represents the only large area with significant potential for development on the island. In the hills, there are no known biological or cultural conflicts. The existing project is visible from the coastal tourist developments in the area, but additional development is unlikely to face additional opposition. A map showing the approximate location of the existing project sites is provided in Appendix H.

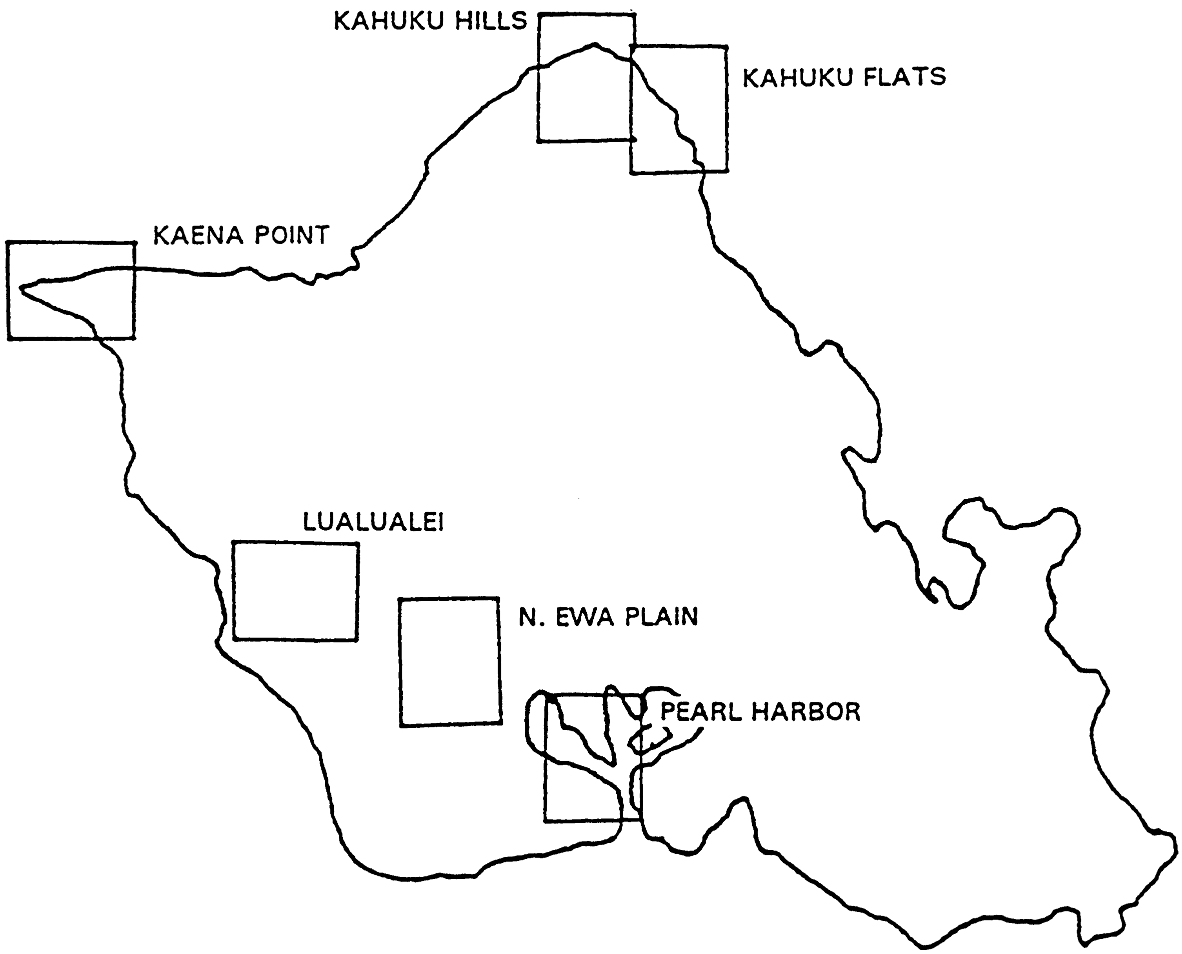

Figure 4. Oahu Project Sites

W2: Kahuku Flats. The Kahuku flats are likely to be somewhat more difficult to develop than the hills. This area is also owned by the Campbell Estate and the potential project site is within the area designated for aquaculture. Some of the area in the flats is off-limits to development because of environmental restrictions, and the visual impact of turbines installed in this area will need to be given careful consideration. There are scattered wetlands in the vicinity and the James Campbell National Wildlife Refuge is an important biological resource area that provides a habitat for all four endangered Hawaiian waterbirds. The Hawaii Statewide Trail and Access System plans to develop a trail along the beach. This trail is listed as high priority because the Kahuku shoreline is one of the last undeveloped coastal wilderness areas remaining on Oahu. Although this is a relatively unpopulated area, there are tourist developments including hotels and golf courses nearby. Even with the obvious restrictions stated, expanding wind power generation in the Kahuku area is the most likely place for wind power development on Oahu. Appendix H includes a map showing the location of a potential project on the Kahuku Flats.

Table 13. Oahu Wind Projects

Island	Technology	Ranking Code	Description
Oahu	Wind	W1	Kahuku Hills
Oahu	Wind	W2	Kahuku Flats
Oahu	Wind	W3	Kaena Point
Oahu			Small-Scale Applications

W3: Kaena Point. The higher ground of Kaena Point has also been identified as a high wind area. The land is owned by the state and currently zoned for agriculture. This site is limited by severe environmental restrictions near the shoreline, although some development may be possible in the higher, more exposed areas. A portion of this area is used by the military as a communications facility. There is limited transmission in the vicinity and an additional line would have to be added for any project greater than 2 MW. Public opposition is likely due to the remote, undeveloped nature of the area. As a result of these factors, this project is considered to be significantly less likely than additional development in the Kahuku area. A map showing a potential project site is provided in Appendix H.

Solar

Oahu's solar resource is concentrated on the leeward side of the island, primarily in areas of urban development. Potential project sites are listed below. Other areas that were considered and eliminated include Kahuku Point (wind and conflicting land uses) and Waialua (low insolation). Table 14 lists the potential solar projects for Oahu.

Table 14. Oahu Solar Projects

Island	Technology	Ranking Code	Description
Oahu	Solar	S1	Pearl Harbor Blast Zone
Oahu	Solar	S2	Lualualei
Oahu	Solar	S3	North Ewa
Oahu	Solar	S4	Ewa Plain
Oahu			Small-Scale Applications

S1: Pearl Harbor Blast Zone. Although the southern region of Oahu is recognized as having significant solar resources, existing urban development prohibits the consideration of a large solar facility. The Blast Zone, the area within a radial distance of 7,405 feet of the munitions magazines located on the West Loch of Pearl Harbor, is largely undeveloped due to the Navy's restriction that no occupied structures be constructed in that area. A solar energy conversion facility could be constructed in this area, with the control facility located beyond the borders; however, the Navy's position regarding the construction of a solar energy conversion facility on this land has not yet been ascertained. The entire area is nearly level and zoned for agriculture. Existing land uses in the vicinity include sugar cultivation and a golf course. The site is centrally located to HECO's load and a number of 46 kV transmission lines exist in the vicinity; however, they are heavily loaded and a transmission upgrade may be necessary for project development to occur. The area provides an important ecosystem for waterbirds, but a solar facility is unlikely to have a significant impact. Due to the developed nature of the region, public opposition is unlikely. Despite the complications of developing a project on military land, this site is ranked highest of the Oahu solar sites because of its central location and good resource. A map of the area is provided in Appendix G.

S2: Lualualei. The Lualualei area is a large flat valley situated to the west of the Honouliuli Mountains. The most extensive tracts of open land that offer the potential for economical solar generation facilities are on land that is under Navy control at the Navy Radio Transmission facility. It is unlikely that most of these areas would be available for development. The land is relatively flat and zoned for agriculture. Land closer to the water is owned by the Hawaiian Homes trust. At present, conflicting land uses may be an issue for either of the two owners. Changes in military land use may make this a desirable location in the future. There are several 46 kV transmission lines in the valleys, although new generation is expected to require some transmission line additions. Little biological, cultural, or public acceptance conflicts are anticipated. This site is ranked below Pearl Harbor because of its more remote location. A map of the area is provided in Appendix H.

S3: North Ewa Plain. This region includes agricultural sugar fields north of Ewa, particularly those north of Highway H1, along Highway 750. Although the solar resource in this area is lower than the coastal areas, land is perceived to be more readily available for a project of this type than land closer to the coast where the resource is greater. As previously discussed, the replacement of sugar lands would be considered only if the project was significantly more economical. Other competing land uses include urban expansion. The majority of the terrain is gently sloped and the land is owned by the Campbell Estate and the State of Hawaii. There are transmission lines in the vicinity; however, they are heavily loaded. There are no biological or cultural conflicts known to exist. Although this site does not have the complications of development on military land, it is ranked below the first two projects due to its lower resource and the potential for competing land uses in the future. A map showing one potential project site in this area is provided in Appendix H.

S4: Ewa Plain. This site region includes land adjacent to Barber's Point N.A.S. to the east over the entire Ewa Plain. Physically, this is the best area on Oahu for solar development because of excellent solar resources, flat land, and good transmission access. However, the area is slated for major urban expansion, including plans by the landowner, the Campbell Estate, for a major new city. Due to the many proposed conflicting land uses, this site is ranked the lowest of potential solar development areas. Of all choices of land use, a solar facility is perhaps the least valuable; however, the incorporation of a large-scale solar facility into an industrial application is possible despite the lack of available land. Because land has not been identified in this area that could be developed for a solar project, this site is ranked last. However, because the use of solar energy for industrial or commercial applications will be evaluated in later phases of the project, this project was not eliminated. The evaluation of this type of project in this area of Oahu is considered to be representative of projects of this type that could be incorporated in areas throughout the islands.

BIOMASS

Table 15 summarizes the anticipated production for the biomass projects identified on Oahu and they are discussed in more detail below. On Oahu, the many competing uses for potentially available land may limit possibilities for biomass crop projects. However, one biomass project was considered based on the potential conversion of an existing sugarcane plantation.

Table 15. Oahu Biomass Projects

GRASS CROPS

Location	Company	Caneland Acres	Acres Harvested	Production (dry ton)	Annual Production (dry ton/ac/yr)
Waialua	Waialua Sugar Co.	12,054	5,800	127,750	11.0

ORGANIC WASTES

Region	Geographic Area	Organic Waste (dry ton/yr)	Primary Components
Region C	west quarter of the island	317,500	83% of total is dairy, foodwaste, and feedlot

B1: Waialua Sugar. This is the site of the Waialua Sugar Planataion. Both the State of Hawaii and the City and County of Honolulu have expessed an interest in maintaining green spaces on the island and a 4,000 acre biomass plantation has been considered in this area. The production of the proposed project site assumes that all of the active, productive acreage of the Waialua Sugar Plantation are converted to biomass grass-crop cultivation.

Organic Waste. There is currently an organic waste processing facility operating in Waimanalo, Oahu. It draws from organic wastes generated in regions A, B, and F, which collectively comprise most of southern and southeastern Oahu. Region C also produces enough organic waste resource to support the successful operation of an organic waste processing facility. Region C represents southwestern Oahu from the Ewa plain stretching to Kaena point, west of the Waianae mountain range.

HYDRO

No potential hydro projects were identified on Oahu.

WAVE AND OTEC

In this phase, a single project site was chosen for further analysis of wave energy systems on the island of Oahu at the Makapuu Head/Waimanalo area. The project site was chosen based on the existence of resource data with sufficient characteristics for potential development. The area is zoned urban and the site was chosen because of its proximity to a load center. The wave resource has been identified on the northeast and northwest areas of Oahu. Due to the fame of the surfing conditions and the protected shoreline on the northeast coast, it is unlikely that any land-based support for a wave energy project would be permitted. Although the resource is lower, development is more likely to be feasible on western coastline, closer to the load centers and transmission access.

Due to a number of factors including current land use, near shore bathymetry (depth measurement), and location both in terms of ocean access and proximity to utility power generation plants, Kahe Point has been studied as the next potential location of research and demonstration projects for OTEC technology. In addition to this site, potential locations for OTEC facilities have been identified off the northeast coast near Kaneohe.

The wave and OTEC sites are listed in Table 16.

Table 16. Oahu Wave and OTEC Projects

Island	Technology	Ranking Code	Description
Oahu	Wave	WV1	Waimanalo
Oahu	OTEC	O1	Kahe Point

KAUAI

The land availability screening process eliminated the vast majority of Kauai's land from consideration. The central mountain regions of Kauai are zoned conservation and are largely park and forest reserve lands. These and most other conservation lands are inaccessible for energy project development. The majority of the north side of the island was eliminated due to zoning, terrain constraints, and no utility access. The majority of Kauai's remaining land is coastal areas with either urban or tourist development. The population density of Kauai is highest at Lihue and Kapaa on the eastern side of the island, and the majority of the land in this area is committed to other uses. As a result, locating energy projects near the energy load is difficult.

Due to the impact of Hurricane Iniki, it is also more difficult to project the future electricity demand in Kauai than for most of the other islands. Also, other than for biomass and hydroelectricity, the use of renewable energy for electric power remains largely unexplored and limited resource data are available. Although Kauai appears to have sufficient resources, it was difficult to find acceptable project sites for development of renewable energy projects. Potential renewable energy projects are discussed in the following section for each technology. The general locations of potential project sites are shown in Figure 5.

Due to overloading conditions that occurred prior to Hurricane Iniki along the transmission line passing through southern Kauai, there is a plan to upgrade the transmission capacity in this area by installing a 69 kV transmission line. So, while there is not currently any surplus transmission capacity, it is anticipated that the addition of a new transmission line will allow additional installed capacity in southern Kauai. The transmission line that runs across northern Kauai is also a 57.1 kV line with a planned upgrade to 69 kV. Based on information from before the hurricane, there is some limited available capacity for power generation additions along the northern transmission corridor.

WIND

On Kauai, the trade winds are forced to flow around the central mountain mass of the island. The prime wind resource appears to be on the southeastern and northeastern coasts of the island. However, there has been limited wind resource assessment on Kauai. Unfortunately, the coastal areas are either developed for tourism or planned for urban expansion. As a result, there is very limited land available for potential renewable energy projects to be developed on Kauai. Potential wind energy projects are listed in Table 17 and discussed below.

W1: N. of Hanapepe. North of Port Allen and Hanapepe, there are mountain gorges that are thought to act as funnels, concentrating the effect of wind in a local area. The land in this area is zoned as agricultural land, but due to the terrain and soil type, is of little value for agricultural purposes. The land is owned by Gay and Robinson. Although the landowner is considering possible ecotourist activities in the vicinity, planned uses are not yet determined. The terrain is fairly complex and potential project sites are between 3 and 5 miles from the nearest transmission line. There are no known environmental or cultural conflicts and the project is unlikely to be visible from any tourist or populated areas. A map showing a potential project site is provided in Appendix I.

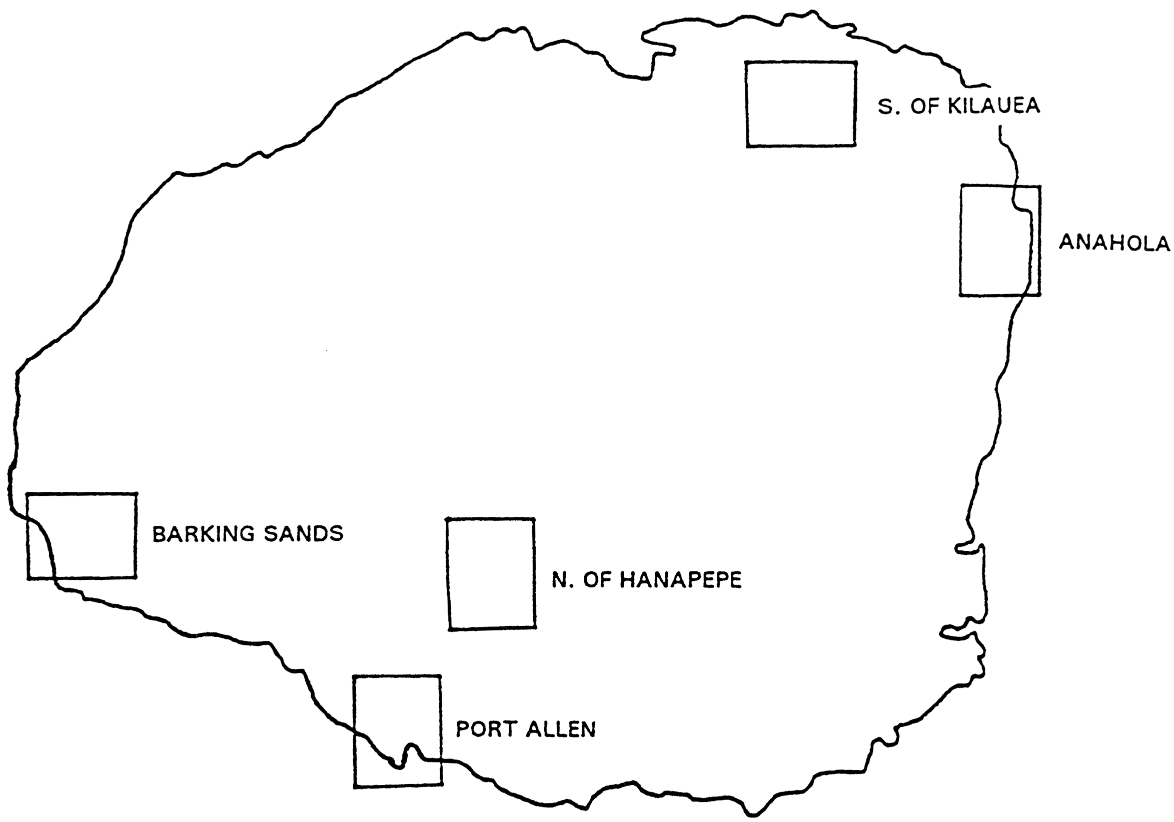

Figure 5. Kauai Project Sites

Table 17. Kauai Wind Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
KAUAI	WIND	W1	N. OF HANAPEPE
KAUAI	WIND	W2	S. OF KILAUEA/ANAHOLA
KAUAI	WIND	W3	PORT ALLEN
KAUAI	WIND	N/A	SMALL-SCALE APPLICATIONS

W2: S. of Kilauea/Anahola. High winds have been measured at the Kilauea Point Coast Guard Station; however, a nearby bird sanctuary and existing homes eliminate this vicinity from consideration for a wind energy project. There are no other wind data in this general area. Although it is suspected that the wind drops off considerably further inland, there may be sufficient wind for a project in some locations to the south of Kilauea and to the east of Kilauea in the Anahola area. Although the land in this area is zoned for agriculture, most of it is developed for luxury homes. The only land that was determined to be available for consideration of a wind energy project was several inland parcels owned by C. Brewer and Co., Ltd. and the Hawaiian Homes land near Anahola. At this time, the resource is unknown on these land parcels; however, should sufficient resource exist, they appear to be developable in terms of terrain, transmission access, and environmental and cultural conflicts. Maps showing the areas are provided in Appendix I.

W3: Port Allen. The Salt Pond Beach Park and Port Allen Airport are located on a peninsula that is zoned as an urban district, but adjacent to the airport is sufficient undeveloped land to site a small wind energy project. The airport is currently used for helicopter flights. The wind resource is estimated to be at the low end of the acceptable range for wind energy conversion; however, due to the limited number of potential projects on Kauai, the evaluation of this site will be considered further. A map is provided in Appendix F.

SOLAR

Southern Kauai exhibits good solar resources; however, there is a limited amount of land available in the Lihue-Poipu-Hanapepe area due to tourist development and urban housing. Only one site was considered for large-scale solar development. It is summarized in Table 18 and discussed below.

Table 18. Kauai Solar Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
KAUAI	SOLAR	S1	BARKING SANDS
KAUAI	SOLAR	N/A	SMALL-SCALE APPLICATIONS

S1: Barking Sands. The only location on the island of Kauai where data indicate that the solar resource sufficient to consider utility-scale solar energy conversion and sufficient land is available is in west Kauai in the vicinity of the Barking Sands Pacific Missile range. Toward the mountains, but still on the plain, the land is zoned for agricultural use. Some of the agricultural land is of limited value as cropland, and so, may be suitable for solar development. In addition, although the federal property of the missile range is zoned as limited conservation, the fact that there is an existing commercial-scale solar water heating unit on the property makes it likely that some kind of solar power station could be developed there as well. The area is a flat sedimentary plain with a high water table, which would have to be considered for any type of development. The Missile range is federally owned and the remaining property in the area is owned by the State. A transmission line runs through the area; however, there is very little existing or projected load growth. As a result, the utility does not consider this to be a desirable location for a generating facility on Kauai. In addition, there are significant biological (primarily waterbird habitat) and cultural (burial grounds) areas in the vicinity that may result in public opposition. Nonetheless, there is a significant amount of land in the vicinity, and a number of potential conflicts should be avoidable through flexible siting. A map showing the general area and one potential project site is included in Appendix I.

BIOMASS

Table 19 summarizes the characteristics of the potential biomass projects identified on Kauai. The projects are discussed in more detail below. Maps showing the location of the proposed energy crop projects for various species are included in Appendix J.

B1: Lihue Plantation. Although this project site is currently planted in sugar, it has fairly low productivity and thus, more probability of considering alternate crops for cultivation. The site is also located near a deep water harbor which may be beneficial for potential transportation fuel projects. The land is owned by Amfac Inc./JMB Hawaii. This is one of two projects on Kauai that was considered for both grass and tree crops.

B2: Olokele Sugar. This site is owned by C. Brewer and Co., Ltd. and located near Kaumakani on the southwest region of Kauai. It is currently planted in sugar. It is also located fairly close to a barge port at Port Allen; however, the land is less productive than the Lihue Plantation for trees. The site was also considered for grass crops. Gay and Robinson land, which is used for sugar but does not have a processing facility, was also considered for a grass crop but was combined with Olokele because they currently use Olokele mill and it was assumed that this arrangement would continue if another crop was cultivated.

Table 19. Kauai Biomass Projects

TREE CROPS

Location	Company	Acres Considered	Productivity Range (dry/ton/ac/yr)	Acres	Annual Production (dry ton/yr)
Lihue	The Lihue Plantation Co.	24,050	13-18	0	0
			11-13	7,223	82,920
			8-11	8,777	83,120
Kaumakani	Olokele Sugar Co.	32,261	13-18	0	0
			11-13	2,367	26,650
			8-11	6,815	59,260

GRASS CROPS

Location	Company	Caneland Acres	Acres Harvested	Production (dry ton)	Annual Production (dry ton/ac/yr)
Lihue	The Lihue Plantation Co.	11,220	6,971	119,100	8.5
Kaumakani	Olokele Sugar Co.	4,716	2,305	70,400	15.3
	Gay & Robinson, Inc.	2,716	1,324	46,170	17.4
Kekaha	Kekaha Sugar Co.	8,294	3,589	98,830	13.8
Eleele	McBryde Sugar Co.	7,015	5,208	93,270	17.9

ORGANIC WASTES

Region	Geographic Area	Organic Waste (dry ton/year)	Primary Components
Region M, N & O	Eastern half of the island	80,265	90% of total is green , foodwaste, & dairy

B3: Kekaha Sugar. This project is located in the southwest region of Kauai near Kekaha. Only grass crops were deemed to be suitable for this site. The land is owned by Amfac Inc./JMB. The grass crop sites were ranked lower than the projects that have more flexibility in species production (tree and grass crops).

B4: McBryde. This project site is also located in the southwest region of Kauai near Eleele. It is currently planted in sugar and owned by Alexander and Baldwin, Inc. Only grass crops were considered at this site and it was ranked lower than Kekaha because of its lower productivity.

Organic Waste. It is estimated that collecting and combining the organic waste generated in the eastern half of Kauai would provide enough waste to be processed to make an organic waste processing facility a viable option on the island of Kauai. An additional option for organic waste that has been explored on Kauai is the use of the boilers at sugar facilities for the burning of waste products. Although this is technically viable, the Department of Health has expressed concerns over the emissions. As an alternative, several plantations have examined the possibility of burning only green waste, which should be considered as a biomass product under their existing permits. Work in this area is in progress and the results will be included in our future work.

HYDRO

Kauai currently produces more hydroelectricity than all the other Hawaiian islands combined. Additional resource potential exists in the river valleys of the northern and eastern portion of the island; however, all proposed projects have been strongly opposed. According to Kauai County planners, all of the remaining streams in Kauai are likely to be designated as special streams, which will prohibit development, with the exception of the Wailua River. On Kauai, most of the existing hydro facilities have been evaluated or are under study for potential upgrades and additional upgrades were determined to not be feasible above those either recently completed or in process. Because all the new hydro proposed for Kauai have been denied permits, it is unlikely that any additional hydro will be allowed on Kauai. However, two potential projects are still attempting development: one on the Wailua River and one on the Hanalei River. Although it is expected to face public opposition, the most likely of these to be developed is shown in Table 20 discussed in more detail below.

Table 20. Kauai Hydro Projects

ISLAND	TECHNOLOGY	RANKING CODE	DESCRIPTION
KAUAI	HYDRO	H1	WAILUA RIVER

H1: Wailua River. Potential hydro projects have been proposed for both the upper and lower Wailua River. The upper Wailua River is dependent on the Hanalei River, however, which is likely to be designated as a special stream by the State of Hawaii. Only the lower Wailua is considered to have any development potential. Development of this project may conflict with existing recreational uses of the river. Until stream designations and development standards are determined, any hydro potential is likely to be stalled. It is expected that a facility with a capacity of approximately 6 MW could be installed.

WAVE AND OTEC

No specific project sites for either wave or ocean thermal on Kauai were identified in this phase of the project. Previous work on the siting of OTEC projects, conducted by PICHTR, indicate that there is sufficient resource (i.e., appropriate bathymetry) for two to three floating OTEC plants off the northern and southern coastlines. One proposed location, near Hanalei is likely to face substantial public opposition. Projects sites near Lihue and Port Allen are more centrally located relative to the load centers and more likely to be developable.

A wave resource has been shown to exist along the northern shore of Kauai. The scenic beauty and protected resources of this area will likely result in significant public opposition to any land-based systems. In addition, limited transmission access exists in this area. Potential for wave energy facilities may be easily sited near Kapaa on the eastern coastline.

SECTION 3. MONITORING PLAN

The purpose of this monitoring plan is to develop a high-quality database that characterizes the wind and solar energy resources in the State of Hawaii in areas that appear to have project development potential. This goal is to be accomplished by identifying potentially developable project sites as described in the previous section, utilizing existing data to the fullest extent practical to characterize these sites, and installing and operating meteorological data monitoring stations where high-quality data are not available. The monitoring stations are to be operated for a minimum of one year.

The approximate equipment costs associated with this monitoring plan total $61,804, which includes 9 wind monitoring stations, 6 solar monitoring stations, and the hardware and software to transfer the data to an IBM PC. The breakdown of costs per monitoring station, and the overall cost for new equipment are shown in Tables 21 and 22. Equipment specifications and cost quotes from the equipment manufacturers for the monitoring equipment recommended for this program are included in Appendix K.

MONITORING STATIONS

In a previous study for the DBEDT entitled *Comprehensive Review and Analysis of Hawaii's Renewable Energy Resource Assessments*, RLA identified, characterized, and compiled the available wind and solar resource data throughout the State of Hawaii. Existing data and currently active monitoring stations were identified based on both that review and continued research to identify additional data sets that were not available when the review was complied. The location of monitoring stations with high-quality data were compared to the wind and solar project sites identified with development potential in order to determine recommend sites where additional monitoring efforts would be useful in characterizing the performance of a project in these sites.

Table 21. Equipment Costs per Monitoring Station

WIND STATION **EQUIPMENT DESCRIPTION**	**90' TOWER** NRG 9200-21
LOGGER WITH SPEED & DIRECTION [1]	$1,610
SECOND ANEMOMETER (CALIBRATED)	NC
EXTRA EPROM (256K)	$40
SHELTER BOX	$85
TOWER (STAINLESS STEEL)	$1,650
GROUND KIT	$50
SUBTOTAL PER STATION	$3,435
DISCOUNT	25%
TOTAL PER STATION	$2,576

[1] CONFIGURED WITH CALIBRATED ANEMOMETER(S) AND 256K HIP(S).

SOLAR STATION **EQUIPMENT DESCRIPTION**	**ASCENTION TECHNOLOGY**
RSR UNIT	$5,700
TRIPOD	$275
MISC. MATERIALS	$115
SHIPPING	$190
TOTAL PER STATION	$6,280

Table 22. Monitoring Equipment Cost Summary

EQUIPMENT DESCRIPTION	NRG 9200-21 [1]
90' WIND STATIONS (2 ANEMOMETERS) - 9 SITES [2]	$25,051
DIRECT RADIATION STATIONS - 5 SITES [3]	$31,400
CHIP READER AND ANALYSIS SOFTWARE	$970
TOTAL EQUIPMENT COST	$57,421
OPTIONAL LANAI STATIONS - GLOBAL RADIATION STATION	$1,440
SUBTOTAL WITH OPTIONAL EQUIPMENT [4]	$58,861
FEE AT 5%	$2,943
TOTAL EQUIPMENT COST	$61,804

[1] COST INCLUDES 2 EXTRA EPROMS FOR PROJECT.
[2] ONE STATION DOES NOT REQUIRE A TOWER.
[3] QUOTES ARE PER J. AUGUSTYN FOR ASCENSION TECHNOLOGIES EQUIPMENT.
[4] ALL VALUES INCLUDE THE 25% DISCOUNT AND SHIPPING COSTS.

The data sets identified as useful for this study in characterizing the resource of potential project sites are not necessarily inclusive of all data collected in the vicinity of these locations. Many short-term studies have been conducted that document site wind or solar resource characteristics; however, in cases where the data quality was questioned, these data were not considered to be sufficient for accurate energy projection estimates. In some cases, data exist that represent the renewable energy resource at a site, but they are not available to the public. In these cases, the value of further data collection was assessed based on the ability of the data to increase the understanding of the site resource and increase the likelihood that the site will be developable in the future. In recommending locations for additional monitoring sites, the main criterion considered was whether additional data would promote the development of a renewable energy project in the future.

Existing high-quality data sets were obtained from a variety of sources including the Hawaiian Sugar Planters' Association, National Climatic Data Center, Hawaiian electric utility companies, the University of Hawaii, project developers, and private landowners. A summary of the characteristics of the existing data that are planned to be incorporated into this program is contained in Appendix L. In some cases, data collection is no longer continuing. However, if several years of high-quality data were available, additional monitoring in a specific location was generally not recommended. In cases where data collection is continuing, the historical data will be obtained as will the data collected during the planned monitoring program. The intent is to make available to the public high-quality data sets from both the existing and proposed monitoring stations near developable land sites.

The following sections describe the recommended monitoring plan on an island by island basis. Figures 6 through 11 contain maps depicting the potential project sites for wind and solar resource assessment and the locations of existing and proposed monitoring sites that will be incorporated into this program. The associated tables summarize the existing and proposed data sets to be used for wind and solar resource assessment. Detailed site maps for each project site can be found in the appendices of this report.

HAWAII

The existing and proposed monitoring sites for Hawaii are shown and described in Figure 6. Four potential wind energy development sites were identified for Hawaii in the previous section. Of these, additional monitoring is recommended at two sites: North Kohala and Lalamilo. There are no suitable wind data currently available at North Kohala. At Lalamilo, data are being collected by private developers; however, they are not publicly available. The proposed monitoring station at this site is recommended for a location further upwind than the current wind farm to further quantify the resource in that area. For the other two project sites, sufficient data were determined to exist and it appears likely that these data will be available to incorporate into the program.

Three potential solar project sites have been identified. Six existing solar monitoring stations are shown in Figure 6, of which four are currently collecting both global and direct solar radiation data. As a result, additional solar monitoring is recommended only at North Kohala. RLA will ensure that the existing monitoring stations are calibrated and will obtain past data sets as well as collect data on a continuing basis.

MAUI

The existing and proposed monitoring sites for Maui are shown and described in Figure 7. Four potential wind energy development sites were identified for Maui. Of these, additional monitoring is recommended at three sites. Monitoring is not recommended at the West Maui site because the site has been extensively monitored by a private developer. Even though these data may not be publicly available, additional data in this location will not serve to further project development. To represent the northwest slope of Haleakala, monitoring is recommended at the NifTAL facility site so as to use an existing tower and reduce equipment expenses.

Figure 7 depicts three existing data sets of global solar radiation data useful for this project. At the PVUSA satellite project, RLA proposes to supplement the existing global radiation data collection efforts by obtaining direct and diffuse radiation data. Solar monitoring is also proposed for the old Maui airport site at Puunene.

MOLOKAI AND LANAI

The existing monitoring sites for Molokai are shown and described in Figure 8. No additional monitoring sites are proposed for Molokai. One existing wind station provides information as to west Molokai's wind resource, and global and direct solar data have been collected near Palaau.

The existing monitoring sites for Lanai are shown and described in Figure 9. Existing data include global solar data collected at two locations on central Lanai. No additional monitoring sites are proposed for Lanai.

OAHU

The locations of existing and proposed monitoring locations for Oahu are shown and described in Figure 10. Three potential wind energy project sites were identified on Oahu. In the Kahuku Hills, additional data collection was not recommended because a large amount of private data already exists. The publicly available Opana data will be used to estimate production in this area. Additional monitoring was recommended at the two other potential wind energy project locations.

Solar monitoring stations are proposed to represent the Pearl Harbor Blast Zone area near the West Loch. Existing solar data will be used to represent the other identified project sites.

KAUAI

The locations of existing and proposed monitoring locations for Kauai are shown and described in Figure 11. There has been very little resource assessment data collection activity in the past. Three potential wind energy projects were identified and two are recommended for additional monitoring.

HAWAII WIND

Project Site	Data Site	Time Period	Anemometer Height	Contact Organization
Lalamilo Wells	Kawaihae	12/90 to 8/92	10,37, &64 meters	HECO
	Lalamilo Wells	proposed	90 feet	
North Kohala	North Kohala	proposed	90 feet	Chalon
Kahua Ranch	Kahua Ranch	4/92 to present	90, 140 feet	Kahua Ranch
South Point	South Point	6/87 to present		Kamaoa Wind Farm

HAWAII SOLAR

Project Site	Data Site	Time Period	Data Type	Contact Organization
Waikoloa	Kawaihae	12/90 to 8/92	global	HECO
	Puuanahulu	1/92 to present	global	HECO
	Kiholo Bay	mid 91 to present	global; direct	Bakken
	Waimea	4/93 to present	global; direct	Bakken
	Mauna Lani Resort	4/93 to present	global; direct	Bakken
Keahole Point	Keahole	3/93 to present	global; diffuse	HECO
	Keahole	1985 to 1993	global; diffuse	NELH
North Kohala	Kahua Ranch	1985 to present	global	Kahua Ranch
	North Kohala	proposed	direct; diffuse	Chalon

Figure 6. Existing and Planned Monitoring Sites for Hawaii

MAUI WIND

Project Site	Data Site	Time Period	Anemometer Height	Contact Organization
West Maui	West Maui	1/92 to 6/93	90, 140 feet	Zond
McGregor Point	Maalaea	2/93 to present	10, 37, 64 meters	HECO
	McGregor Point	proposed	90 feet	
Puunene	Puunene	5/92 to present	10 meter	HECO
	Old Airport	proposed	90 feet	
NW slope Haleakala	NifTAL Tower	proposed	90 feet	

MAUI SOLAR

Project Site	Data Site	Time Period	Data Type	Contact Organization
Puunene	Old Airport	proposed	direct; diffuse	
	Puunene	5/92 to present	global	HECO
Kihei	PVUSA	1989 to present	global	PVUSA
	PVUSA	proposed	direct; diffuse	
Kahului	Maui Quarry	5/92 to present	global	HECO
	Mauinet #107	1983 to 1991	global	UH (Agronomy & Soil)

Figure 7. Existing and Planned Monitoring Sites for Maui

MOLOKAI WIND

PROJECT SITE	DATA SITE	TIME PERIOD	ANEMOMETER HEIGHT	CONTACT ORGANIZATION
SMALL APPLICATIONS	WEST MOLOKAI	2/92 TO PRESENT	90 FEET	ZOND/DBED

MOLOKAI SOLAR

PROJECT SITE	DATA SITE	TIME PERIOD	DATA TYPE	CONTACT ORGANIZATION
SMALL APPLICATIONS	PALAAU	6/92 TO PRESENT	GLOBAL	HECO
	PALAAU	1/84 TO 6/86	DIRECT	HECO

Figure 8. Existing and Planned Monitoring Sites for Molokai

LANAI SOLAR

Project Site	Data Site	Time Period	Data Type	Contact Organization
Small Applications	Lanai City	2/92 to present	global	HECO
	Miki Basin	10/90 to present	global	HECO
	Manele Bay	proposed (optional)	global	HECO

Figure 9. Existing and Planned Monitoring Sites for Lanai

OAHU WIND

Project Site	Data Site	Time Period	Anemometer Height	Contact Organization
Kahuku Hills	Opana	3/76 to 2/83	37 feet	UHMET
Kahuku Flats	Kahuku Flats	proposed	90 feet	
Kaena Point	Kaena Point	proposed	90 feet	

OAHU SOLAR

Project Site	Data Site	Time Period	Data Type	Contact Organization
Pearl Harbor	Pearl Harbor	proposed	direct;diffuse	
N. Ewa Plain	Kunia	1989 to 1990	global	HSPA
Ewa Plain	Campbell Industrial	4/91 to present	global	HECO
Lualualei	Kahe Point	1/86 to 5/87	global	HECO

Figure 10. Existing and Planned Monitoring Sites for Oahu

KAUAI WIND

PROJECT SITE	DATA SITE	TIME PERIOD	ANEMOMETER HEIGHT	CONTACT ORGANIZATION
N. OF HANAPEPE	GAY & ROBINSON	7/85 TO 4/88	APPROX. 20 FEET	GAY & ROBINSON
	N. OF HANAPEPE	PROPOSED	90 FEET	
S. OF KILAUEA/ ANAHOLE	S. OF KILAUEA	PROPOSED	90 FEET	
PORT ALLEN	PORT ALLEN AIRPORT	2/92 TO 1/93	30 FEET	KECO

KAUAI SOLAR

PROJECT SITE	DATA SITE	TIME PERIOD	DATA TYPE	CONTACT ORGANIZATION
BARKING SANDS	BARKING SANDS	PROPOSED	DIRECT;DIFFUSE	
	MCBRYDE	1/91 TO PRESENT	GLOBAL	MCBRYDE SUGAR CO.

Figure 11. Existing and Planned Monitoring Sites for Kauai

An existing wind monitoring station that measured high average wind speeds at Kilauea Point is not shown because it is thought not to be representative of developable wind sites in the area. Additional solar monitoring is recommended at Barking Sands.

DATA COLLECTION METHODOLOGY

WIND RESOURCE MEASUREMENT PLAN

To achieve the objective of a reliable resource assessment, the wind resource database developed in this activity must be highly reliable and accurate and consistent in nature across all sites. The wind data will be collected in a manner consistent with the American Wind Energy Association's *Standard Procedure for Meteorological Measurements at a Potential Wind Turbine Site* and *Recommended Practice for the Siting of Wind Energy Conversion Systems* [25,26].

In order to accurately predict the performance of potential wind energy projects, it is desirable to have data concerning wind speed, direction, and wind shear (change in speed with height above the ground). For nine of the proposed wind monitoring stations, a 90 ft mast tower with data collection at two heights is recommended. Cup anemometers (one at each height) and a single wind vane will be used. A 30 ft tower is recommended for Kaneohe.

FIELD MEASUREMENT EQUIPMENT SELECTION

In order to determine the most appropriate equipment to use for the monitoring program, quotes and product literature were obtained and discussed with well-known manufacturers. Criteria used to decide on the recommended equipment included costs, accuracy, reliability, durability, ease of use, and support from the manufacturer. As a result of this analysis, NRG9200-21 data loggers with two NRG40C calibrated anemometers and one NRG200P direction vane are recommended for use in this project. The data logger and sensors will be mounted on NRG90TT 90 ft or 30 ft tall towers. Hourly average wind speed and most frequent direction will be reported with a resolution of 0.1 mph and 1 direction sector. Data sampling accuracy are +1 -0 mph and ±4 degrees.

FIELD EQUIPMENT TESTING AND INITIAL CALIBRATION

The equipment will be delivered to Hawaii calibrated and ready for installation. Before installation, the sensors will be inspected to verify that they are in proper functioning condition.

FIELD EQUIPMENT INSTALLATION

Siting

Towers will be located at sites representative of the overall resource of the potential project site and consider factors such as prevailing wind direction and surrounding land forms. Measurements will be taken in an open area, free from heavy vegetation and structures. Nominal anemometer heights will nearly be 30 and 90 ft (actual anemometer heights will be measured and recorded).

Installation

Meteorological measurement sites will be installed according to the manufacturer's instructions regarding field installation, including grounding, sensor wire shielding, and weatherproofing the installation. Particular attention should be paid to ensure that the guy wire anchors are appropriate for the soil conditions. An anemometer is mounted at the top, with an associated wind vane oriented so that a "North" indication of the wind vane indicates true-north rather than magnetic north. The 30 ft anemometer will be mounted on a cross-arm attached to the tower at a distance of at least six tower diameters from the tower into the prevailing trade wind direction. The data logger will be attached to the tower at a height that reduces the likelihood of damage from horses or grazing animals, and will be kept locked at all times that it is left unattended. Barbed wire will be used on the guy wires in grazing areas to dissuade cattle or horses from disturbing the equipment.

FIELD EQUIPMENT MAINTENANCE

During each site visit, the following activities will be performed, and information will be recorded on a Maintenance Report Post Card that will be mailed to RLA:

- Record the date, time, and the name of the person conducting the site visit, and the site visited.
- Visually inspect the physical condition of the entire installation and of the general functioning of the sensors for proper appearance and operation. Record/correct any irregularities.
- Visually inspect the tower assembly, including the guy wire tensions, the vertical trueness of the mast, and the condition of the grounding system. Record/correct any irregularities.
- Check the battery voltage. Replace the batteries as needed, per the logger manufacturer's instructions. Record any changes.
- Check the data logger operation according to the manufacturer's instructions.
- Document any other observations and actions taken under the "Comments" portion.

Site maintenance frequency will initially be at bi-weekly intervals. Because the necessary site maintenance frequency depends on site-specific conditions, data from each site inspection will be carefully analyzed to see if less frequent visits can be made without loss of accuracy. In no event will site maintenance visits be made less frequently than once per month.

DATA COLLECTION AND QUALITY VERIFICATION

Data will be collected from site locations on a monthly basis. A back-up copy of the data chip will be made at the time of data collection. Both chips will be labeled with the monitoring site name, date, and time of collection. One chip will be mailed to RLA. The backup chip will be stored until the next month when it will again be used to back-up the data. In the event that the first chip is lost or damaged, there is a backup.

After receiving the chip at RLA, data will be transferred to an IBM computer in ASCII format. The data will be examined for completeness and reasonableness. Any irregularities will be reported to site personnel immediately, whereupon a site inspection and maintenance visit will be performed in order to ensure a high rate of data recovery and high data quality.

High correlation of wind speeds is expected from the two anemometers on each wind monitoring station. In the event that the monthly record from one of the anemometers experiences a low data recovery rate, accurate estimates should be obtained through extrapolation of data from the other anemometer. The use of two anemometers provides redundancy and ensures accuracy as well as providing wind shear information.

DATA PROCESSING

On a monthly basis, RLA personnel will produce data summaries using NRG's EEREADER software. These summaries will include hourly average wind speeds, wind speed distribution, tabulated wind rose, diurnal wind speed variation, information about turbulence, maximum peak gust, and sustained wind speeds.

SOLAR RESOURCE MEASUREMENT PLAN

The goal of this solar resource measurement effort is to develop a high-quality database of solar irradiance measurements at selected sites over a one year period. In a later project phase, these data will be used as the basis on which to compare and assess the potential of certain renewable energy technologies in different areas of the State. In order to predict station performance, data need to be collected for both direct normal (broad band) irradiance (DNI), and global horizontal diffuse (broad band) irradiance (DHI), as well as the more commonly and easily measured total global horizontal (broad band) irradiance (GHI).

To achieve the objective of a reliable technology assessment, the solar radiation database developed in this activity must be highly reliable and accurate and consistent in its nature across all sites. The resulting data must also be of known measurement quality, and be directly traceable to World Meteorological Organization (WMO) radiometric reference standards.

These goals will be met through adherence to the following practices and methods:

FIELD MEASUREMENT EQUIPMENT SELECTION

Several possible equipment types were evaluated for collecting solar data. It was determined that use of LICOR Model 200S pyranometers, fitted with automated rotating shadow band mechanisms that allow direct measurement of GHI and DHI, with DNI directly and accurately calculated, offered the best option with regards to cost and accuracy. Selected overall measurement systems must achieve a total measurement uncertainty within ±7.5% for all three broad band components: DNI, DHI, and GHI. Achievement of desired measurement uncertainties are possible with this equipment provided that accurate initial calibrations are performed, and proper installation and maintenance procedures are followed.

FIELD EQUIPMENT PROGRAMMING, TESTING, AND INITIAL RADIOMETER CALIBRATION

Campbell Scientific Model CR10 data loggers will be used to read and store sensor scans and control the rotating shadow band mechanisms. The CR10's will be programmed to measure GHI and DHI and compute DNI once per minute, and to store averages of these parameters every 15 minutes. All time references will be made in local standard time.

Upon receipt of the data loggers and rotating shadow band radiometer (RSR) units, the LICOR 200S pyranometers associated with each unit will be calibrated at Augustyn & Company, Inc.'s (ACI) radiometer calibration test facility in Albany, California. This calibration test will employ the continuous shaded component summation calibration technique drawn from techniques defined in ASTM test standards E816-81 and E913-82 as further refined by the staff of the Solar Resource Assessment Project at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. This technique provides direct traceability to WMO radiometric reference standards via ACI's and NREL's reference instruments. The minimum calibration uncertainty achievable by the ACI calibration facility is ±2.2% for DNI measurements, and approximately 3.5% for GHI measurements. New calibration factors will be derived for each of the new LICOR 200S pyranometers to be used in this project as a result of this initial calibration.

FIELD EQUIPMENT INSTALLATION

Siting

Field measurement equipment will be located so as to preclude or minimize full or partial direct beam shading of the radiometers at any time of day or year. Also, siting will minimize blockage of the diffuse sky dome by any adjacent structures, objects, or local airborne (optical) contaminants. A detailed description of the site will be provided in the report that will accompany the final data delivery. This report will document any site features that might have affected the readings.

Installation Procedures and Practices

In addition to strict adherence to all manufacturer's instructions regarding field installation, including grounding, sensor wire shielding, and weatherproofing the installation, particular attention will be paid to ensuring that the equipment will be mounted to a very secure base to avoid the possibility that the sensor will drift out of level during the course of the measurement period.

FIELD EQUIPMENT MAINTENANCE

Periodic site maintenance activities will include:

- Visual inspection of the physical condition of the entire installation and of the general functioning of the rotating mechanism for proper appearance and operation.
- Visual inspection and written notes on the appearance of the sensor surface.
- Cleaning the sensor surface with distilled or deionized water and a soft cloth or tissue.
- Completing and mailing a Maintenance Report Post Card, documenting observations and date and time of cleaning.

Site maintenance frequency will initially be at one week intervals. Because the necessary site maintenance frequency depends on site-specific conditions, data from each site inspection will be carefully analyzed to see if less frequent visits can be made while maintaining our overall goal for measurement uncertainty. In no event will site maintenance visits be made less frequently than once per month.

DATA COLLECTION AND QUALITY VERIFICATION

Each monitoring station will be equipped with a telephone modem and phone line. Data will be retrieved automatically each night from each site by a computer in ACI's Albany, California, office. The retrieved data files will then be run through ACI's Data Verification Systems (DVS), which will perform a variety of tests to assess data quality and proper functioning of the site units. Included in these tests will be the two- and three-component solar irradiance data quality control test devised by NREL called "SERI QC." DVS will assign a multi-component data quality flag to each data value retrieved, indicating both the results of tests made and the exact nature of any modification made to a data value. Data will be delivered both with and without data quality flags as generated by DVS.

Once DVS has completed its automatic data quality screening, ACI personnel will review the results, and immediately contact site maintenance personnel if any remedial action is necessary. Daily, automated data collection and quality assessment will therefore minimize the total amount of missing or lost data.

DATA SUMMARIZATION AND DELIVERY

On a monthly basis, ACI personnel will produce data summaries using DVS. These will include daily totals and maximums for each irradiance parameter for each day of the month. Data for all sites will be delivered on diskette on a quarterly basis in ASCII files in MSDOS format. For each site, two files will be delivered, one will contain both the data and the associated data quality flags assigned by DVS, while the second file will contain the data without the flags.

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APPENDIX A

PRELIMINARY LAND ZONING MAPS

APPENDIX B

PRELIMINARY LAND OWNERSHIP MAPS

APPENDIX C

ELECTRIC UTILITY INFORMATION

The following appendix contains information concerning the State of Hawaii's electric utilities, including system transmission maps, diurnal load diagrams, graphs of peak monthly demand, and tables describing the utilities' system resource plans.

APPENDIX D

ENVIRONMENTAL AND CULTURAL RATINGS OF POTENTIAL PROJECT SITES

APPENDIX E

HAWAII SITE MAPS

Hawaii W1	Lalamilo Wells
Hawaii W2 & S3	North Kohala
Hawaii W3	Kahua Ranch
Hawaii W4	South Point
Hawaii S1	Waikoloa
Hawaii O1 & S2	Keahole Point

APPENDIX F

MAUI SITE MAPS

Maui W1	West Maui
Maui W2	McGregor Point
Maui W3	NW Slope of Haleakala
Maui W4 & S1	Puunene
Maui S2	Kihei
Maui S3	Kahului Airport

APPENDIX G

MOLOKAI AND LANAI SITE MAPS

Molokai W1 & S1	West Molokai
Lanai W1	Shipwreck Beach

APPENDIX H

OAHU SITE MAPS

Oahu W1	Kahuku Hills
Oahu W2	Kahuku Flats
Oahu W3	Kaena Point
Oahu S1	Pearl Harbor Blast Zone
Oahu S2	North Ewa Plain
Oahu S3	Lualualei
Oahu O1	Kahe Point

APPENDIX I

KAUAI SITE MAPS

Kauai W1	North of Hanapepe
Kauai W2	Anahola
Kauai W3	South of Kilauea
Kauai S1	Barking Sands

APPENDIX J

BIOMASS PROJECT MAPS

APPENDIX K

EQUIPMENT SPECIFICATIONS AND QUOTES

APPENDIX L

CHARACTERISTICS OF EXISTING DATA SETS